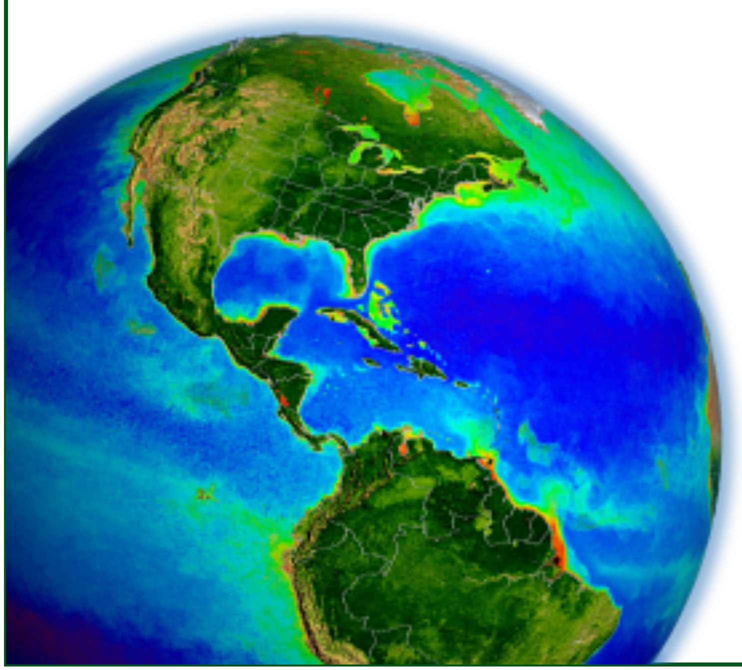
MODIS & VIIRS
Ocean Science Team Break-out



MODIS/VIIRS Science Team Meeting

6-10 June 2016, Silver Spring, MD

Contents

Ocean Break-out Agenda

June 8

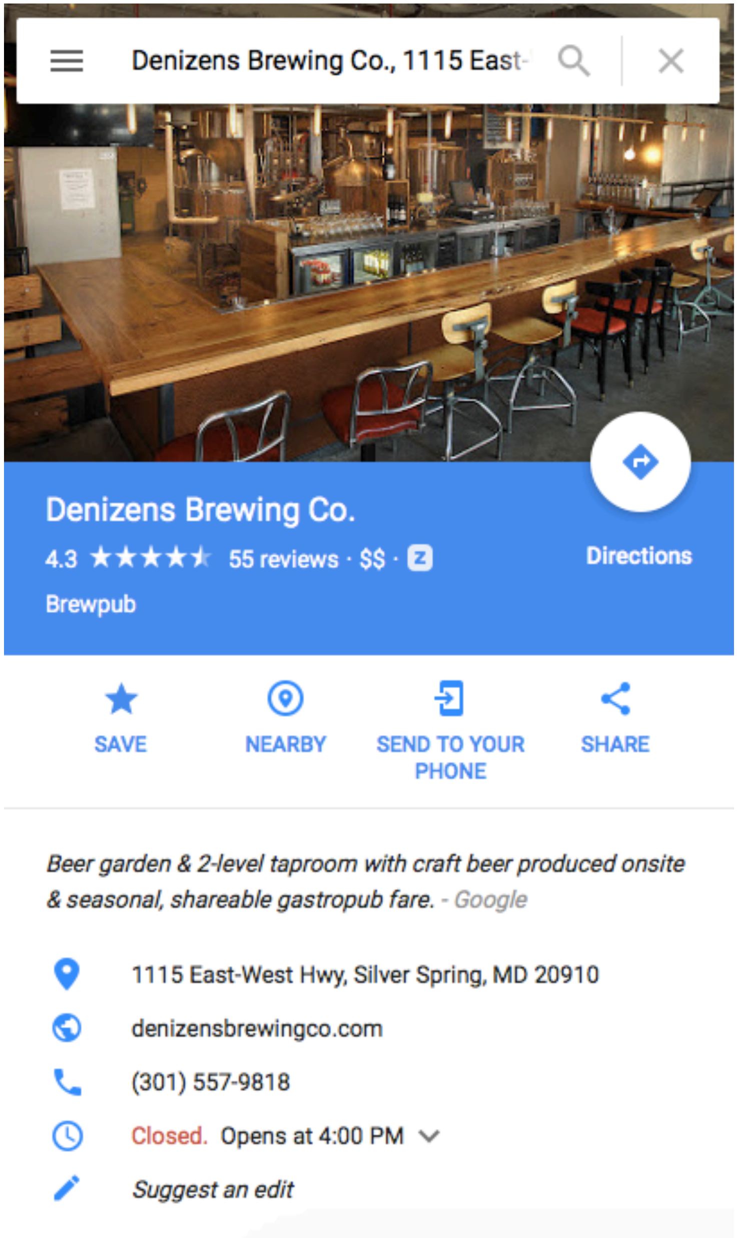
Overview and Status		
1:30	Bryan Franz Sean Bailey Gene Eplee Gerhard Meister Fred Patt	*Overview, MODIS and VIIRS OC & SST production & distribution status, data quality*
Product and Algorithm Updates		
2:00	Chuanmin Hu	*Updates on the OCI Chl Algorithm*
2:20	William Balch	*Current advances (and challenges) with the PIC algorithm*
2:40	Robert Frouin	*Ocean surface PAR product from MODIS and VIIRS data*
3:00	Greg Silsbe (PI Westberry)	*Net Primary Production modeling from satellite (MODIS)*
3:20	Richard Lindsley (PI Wentz)	*VIIRS versus AMSR-2 SST Retrievals: The Effect of Aerosols*
3:40	Prabhat Koner (PI Harris)	*Update on Deterministic Inverse Method for SST Retrieval from VIIRS*
4:00	*Break*	
Discussion		

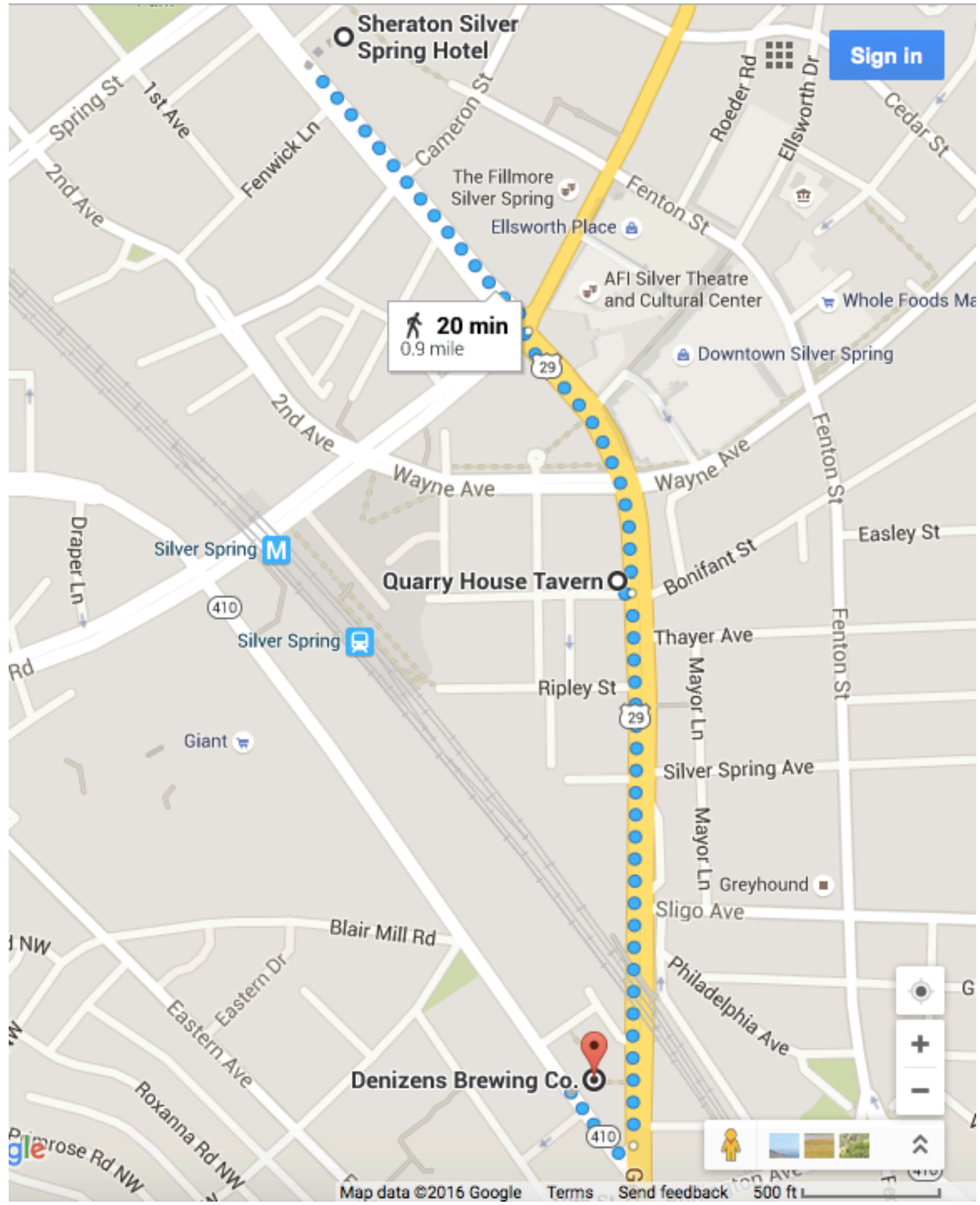
Ocean Break-out Agenda

June 8

Discussion		
4:20	Zhongping Lee	*Band averaged pure water properties*
4:30	Chuanmin Hu	*Chl-specific l2-flag to increase data volume?*
4:40	*Topics* • *questions for Ocean SIPS or OB.DAAC* • *product and algorithm documentation* • *new products?* • *product uncertainties* • *consistency across sensors, data merging from multiple sensors* • *interaction with PACE Science Team* • *organization of future meetings*	

Follow-up Discussions (5:30, Denizens)





A.28 The Science of Terra and Aqua

A.46 Terra and Aqua – Algorithms – Existing Data Products

PI	Proposal Title
Bryan Franz	Ocean Discipline Lead
Barney Balch	Integrating the MODIS PIC Product Into the Climate Data Record Maintenance and Refinement of the MODIS Algorithm for Particulate Inorganic Carbon
Mike Behrenfeld	Global Ocean Phytoplankton Carbon and Physiology With MODIS-Aqua
Scott Doney	Multi-Scale Satellite Analysis of the Biophysical Dynamics Governing Ocean Phytoplankton Community Structure
Bryan Franz	Maintenance and Quality Assessment of Remote Sensing Reflectance, Chlorophyll, and Diffuse Attenuation Products to Support MODIS Ocean Color Science
Robert Frouin	Improvements to the MODIS Standard Ocean PAR Product *Retrieval of Marine Reflectance From MISR Data
Chuanmin Hu	Maximize MODIS Potentials for Near Real-Time Ocean Applications Through Developing and Refining Novel Algorithms and Products Establish a Multi-Sensor Climate Data Record of Ocean Chlorophyll-A Concentrations Using a Novel Algorithm Concept
Zhongping Lee	Development of New Solar Radiation and Primary Production Products from MODIS Ocean-Color Measurements
Peter Minnett	The Forward Solution to Sea-Surface Temperature Retrieval From MODIS Measurements Continued Maintenance and Minor Refinement of Algorithms for Deriving SST From MODIS
Norm Nelson	Bermuda Bio-Optics Project: Continuation of Time-series and Retrospective Data Analysis
Dave Siegel	Plumes and Blooms: A Multi-Decadal Coastal Bio-Optical Time-series and Retrospective Data Analysis
Crystal Thomas/ Antonio Mannino	Support of NASA Ocean Biology and Biogeochemistry Research With Quality Assured HPLC Pigment Analysis
Jeremy Werdell	Advancing the Retrieval of Marine Inherent Optical Properties From Satellite Ocean Color Radiometry
Toby Westberry	A Next-Generation Net Primary Production Model for Application to MODIS Aqua Refinement of Global MODIS Chlorophyll Fluorescence Quantum Yields

A.29 Suomi National Polar-orbiting Partnership Science Team

PI	Proposal Title
Carlos Del Castillo	Ocean Discipline Lead
Barney Balch	Use of Suomi NPP for deriving science data records of ocean particulate inorganic carbon concentration: algorithm improvements, product validation and achieving continuity with the EOS product
Bryan Franz	Extension of the MODIS Ocean Color Time-Series to S-NPP/VIIRS: Marine Remote Sensing Reflectance and Derived Products
Robert Frouin	Development of a Science Quality Ocean Surface PAR Product from NPP VIIRS Data
Watson Gregg	Combining Data Assimilation with an Algorithm to Improve the Consistency of VIIRS Chlorophyll: Toward a Multidecadal, Multisensor Global Record
Andy Harris	New Physically Based Sea Surface Temperature Retrievals for NPP VIIRS
Chuanmin Hu	Refine and Improve Suomi NPP Chlorophyll a and Other Ocean Color Data Products Using a Novel Algorithm Concept
Zhongping Lee	Upgrade the Kd(490) Product to the Normalized Diffuse Attenuation Coefficient at 490 nm (nKd(490)) for Suomi NPP
Peter Minnett	Sea-Surface Temperature from VIIRS - Extending the MODIS Time Series for Climate Data Records
Frank Wentz	Analysis and Mitigation of Atmospheric CrossTalk in VIIRS SST Retrievals

MODIS and VIIRS Ocean Science Team

26 Selected Proposals
16 Unique PIs

Science Team Organization

Program Scientist (S-NPP & MODIS, etc., etc.)

Paula Bontempi

Science Team Leaders

Michael King (MODIS)

Jim Gleason (VIIRS, S-NPP Project Scientist)

Science Team Ocean Discipline Leaders

Bryan Franz (MODIS)

Carlos Del Castillo (VIIRS)

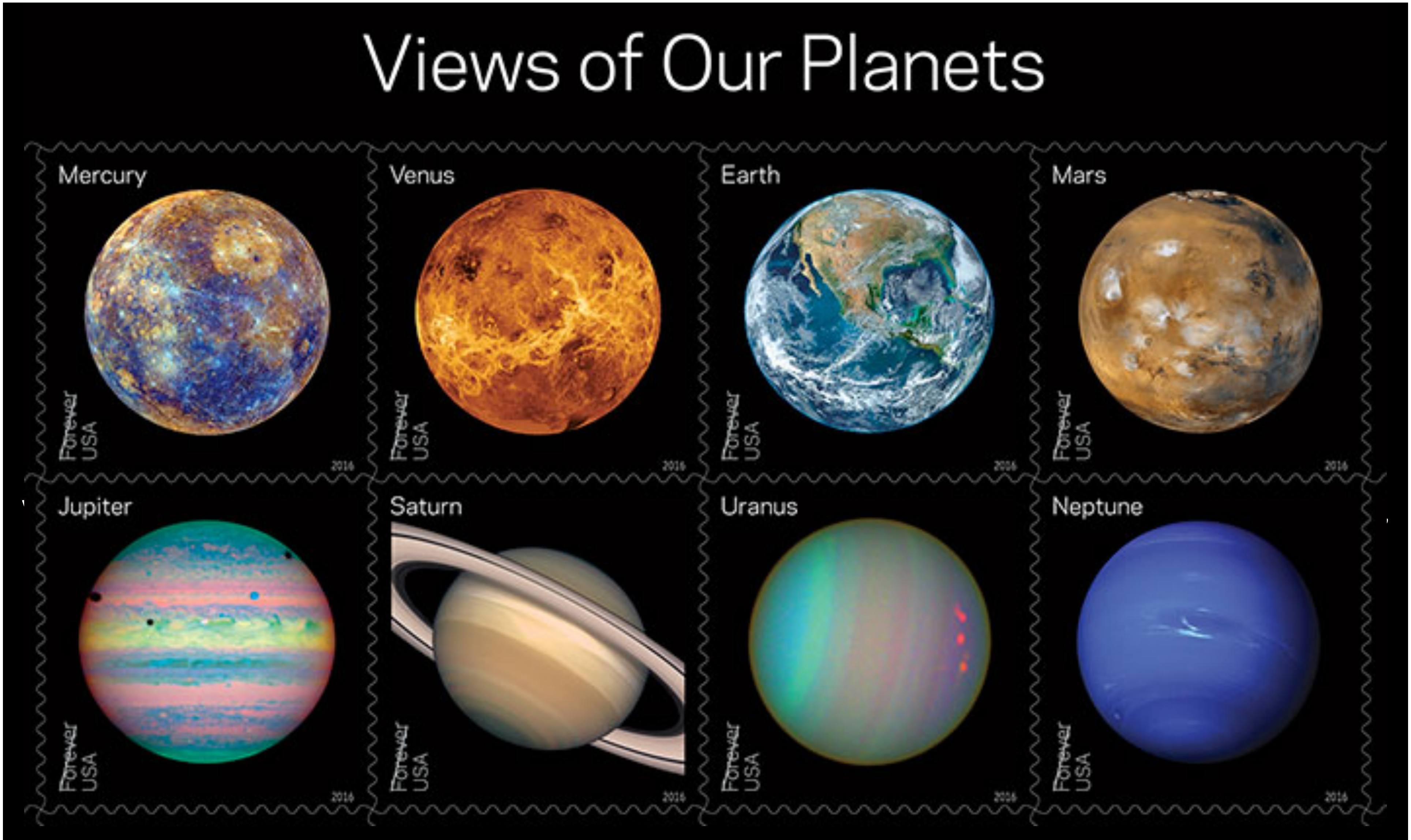
Ocean SIPS (MODIS & VIIRS, Implementation and Processing)

Gene Feldman & Bryan Franz

DAAC (MODIS & VIIRS, Archive and Distribution)

OB.DAAC (Gene Feldman & Sean Bailey, Ocean Color)

PO.DAAC (Robert Toaz & Ed Armstrong, SST)

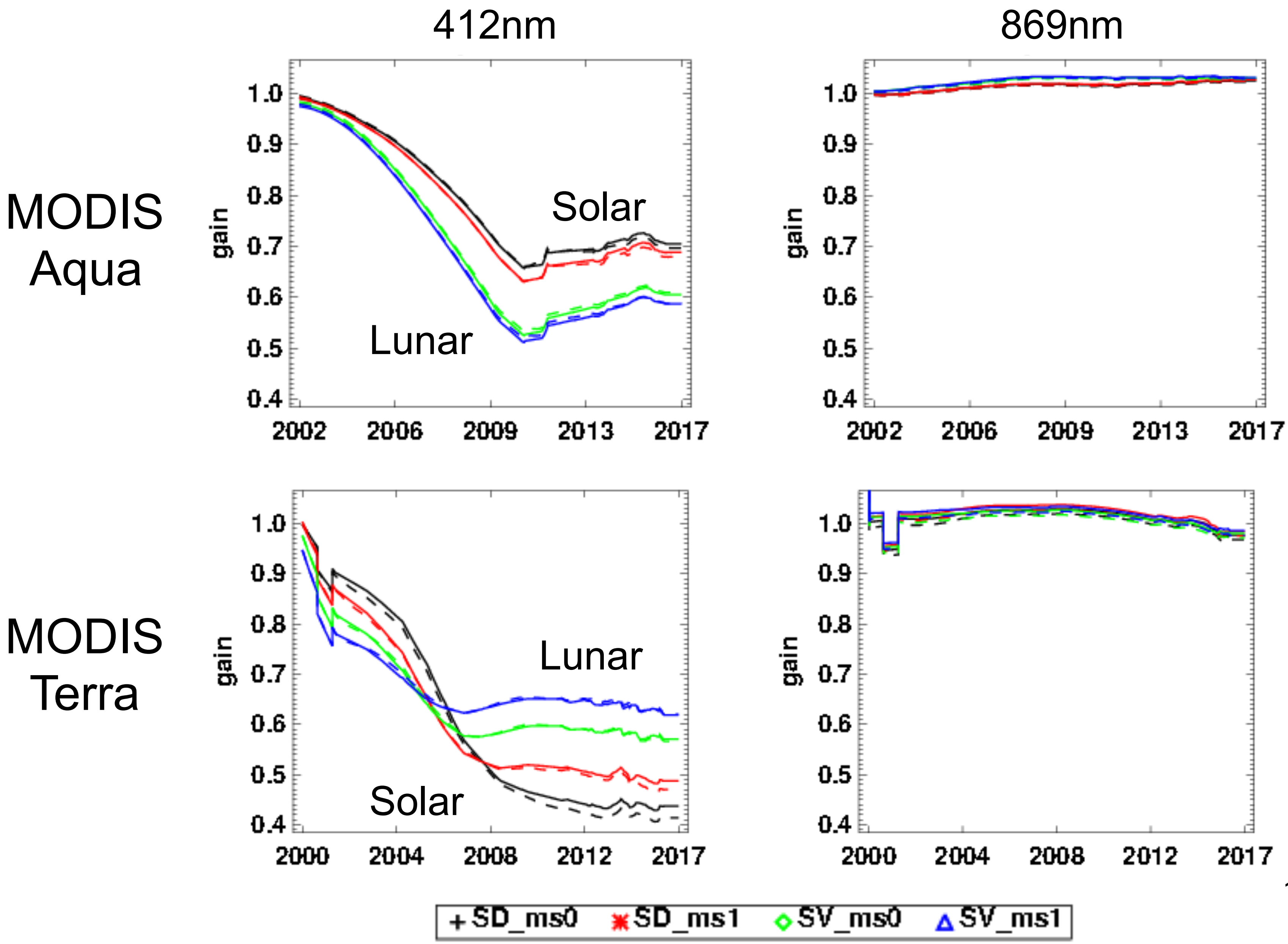


Views of Our Planets” Forever stamps featuring iconic images of the planets in our solar system, including the well-known “Blue Marble” image of Earth” were released on 31 May 2016 at the World Stamp Show in New York City, an international gathering of stamp collectors that occurs only once each decade in the U.S. with more than 250,000 visitors attending.

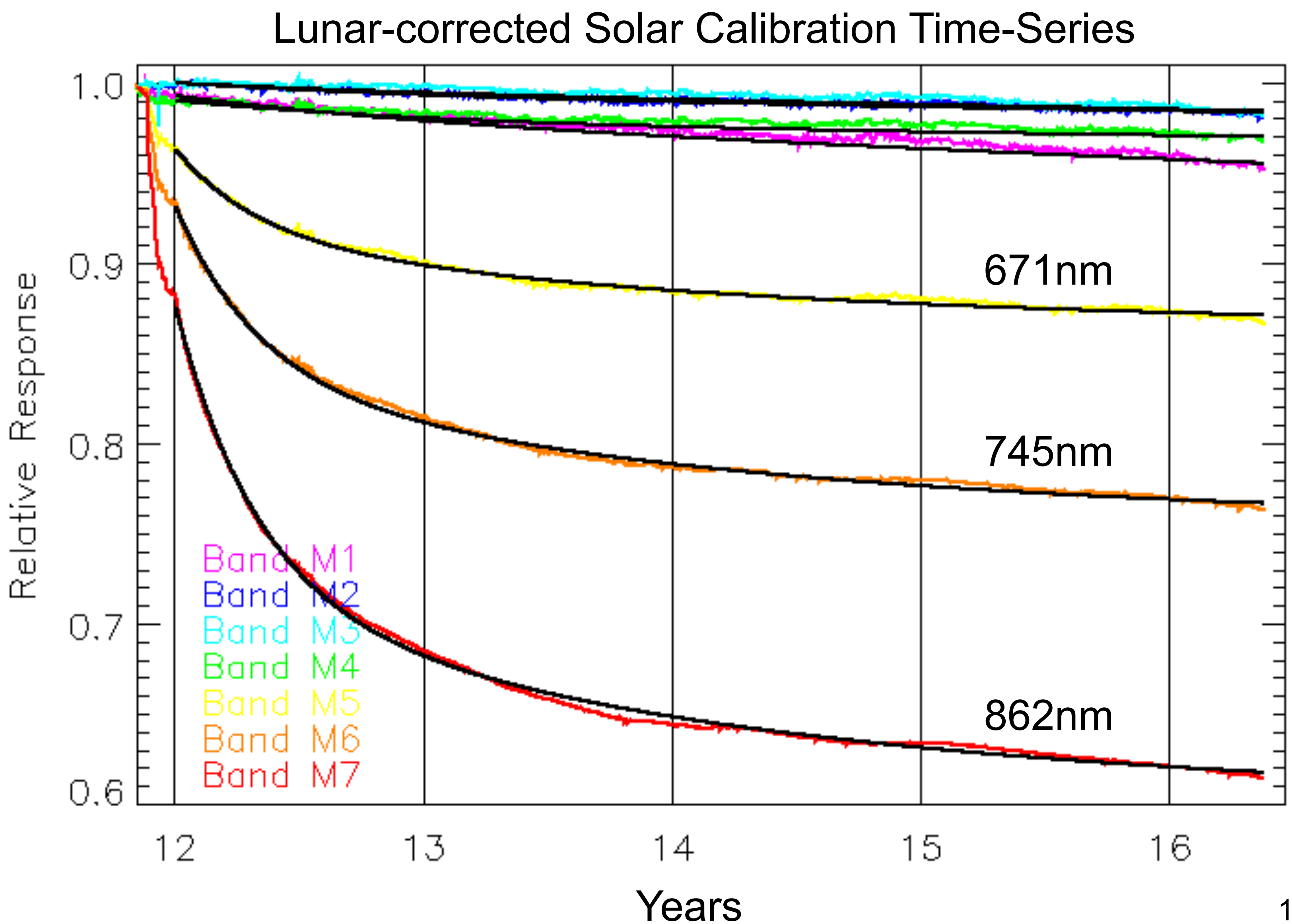
Norman Kuring of the OBPG created the new "Blue Marble" using data taken by VIIRS on the NOAA/NASA Suomi NPP satellite soon after it began orbiting our home planet in 2011.

Instrument Status

MODIS Sensor Degradation



VIIRS Sensor Degradation

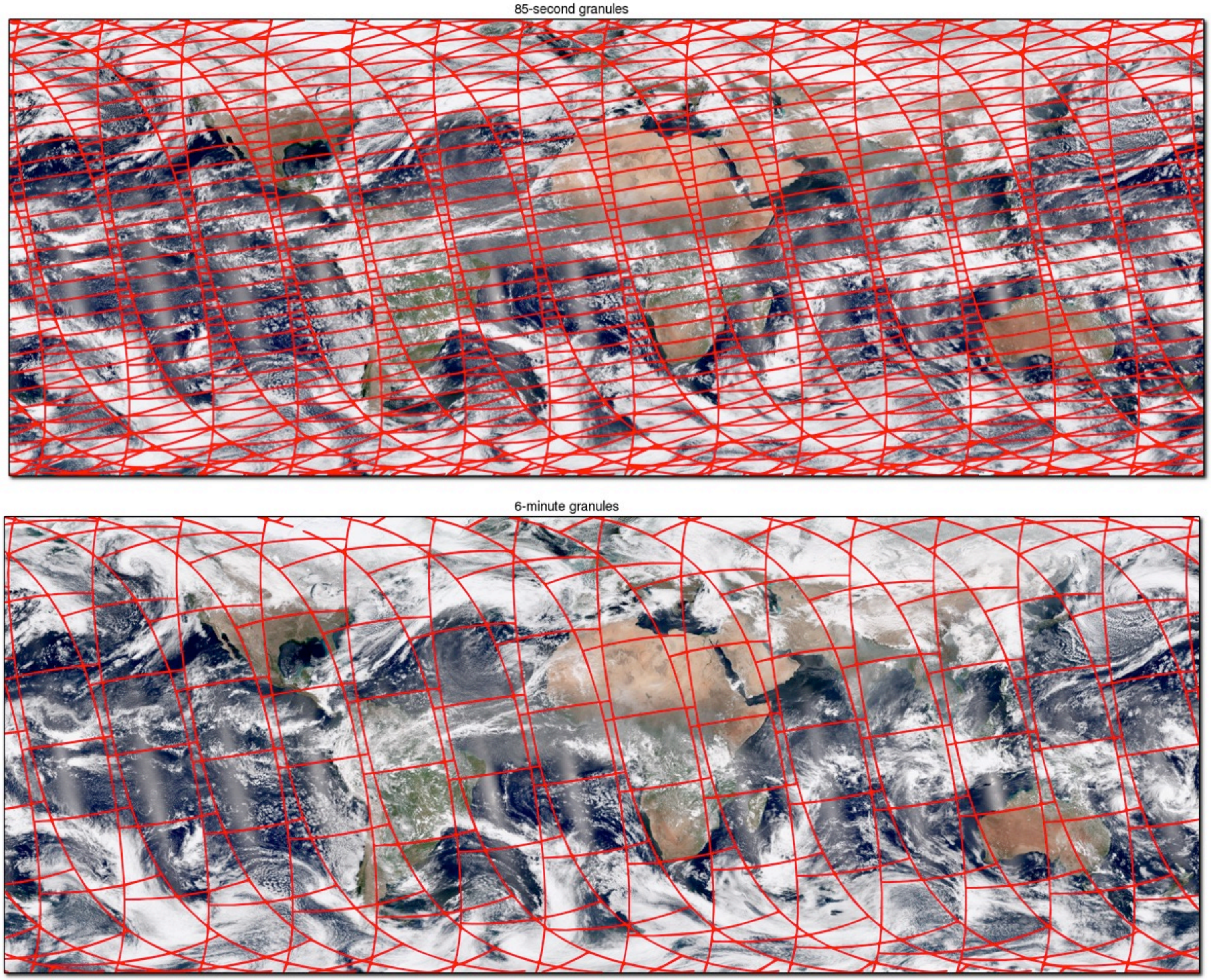


Processing Status

VIIRS Level-1 Redevelopment

VIIRS Data Collected on February 11, 2016

85-second granules



6-minute granules

VIIRS Level-1 Redevelopment

Why did we do this?

- L1 algorithms, software and product formats under NASA control.
  - 6-minute granules instead of 85 seconds.
  - Daily calibrated data files reduced from 22,000 SDRs to 720 L1Bs.
- Significantly improved support for reprocessing.
  - Permanent archive of L1A and geolocation products.
  - Simplify calibration updates and algorithm tests.
- Support for subscene extraction (match-up)
- Raw data feed via NASA (EDOS).

What have we accomplished?

- V1.0 of VIIRS L1 software released in October 2015.
- IDPS raw data feed ended March 2016.
- All VIIRS OC products regenerated April 2016 (version R2014.0.2).

MODIS and VIIRS SST Status

- All three missions have been reprocessed:
  - MODIS/Aqua R2014.0, May 2015
  - MODIS/Terra R2014.0, May 2015
  - VIIRS/SNPP R2016.0, May 2016
- Level-2 and Level-3 format changed to CF-compliant netCDF-4
- A minor issue was identified in the cloud masking decision tree for the MODIS sensors. An update to the code was put in production in the forward stream in March 2016.
- VIIRS implemented a new decision-tree process. MODIS will likely be reprocessed again this year, for consistency (R2016.0).
- RSMAS and SeaBASS team implementing improved in situ match-up process, which will provide an online accessible SST validation data set similar to the ocean color validation data set.

R2014.0 Multi-Mission Ocean Color Reprocessing

Scope

- CZCS, OCTS, SeaWiFS, MERIS, MODIS(A/T), and VIIRS

Motivation

1. improve interoperability and sustainability of the product suite by adopting modern data formats, standards, and conventions (netCDF4, CF and ISO conventions, etc.)
2. incorporate knowledge gained in instrument-specific radiometric calibration and updates to vicarious calibration
3. incorporate algorithm updates and advances from community and Mission Science Teams

Status

- CZCS, OCTS, **VIIRS, MODISA, MODIST**, SeaWiFS (& GOCI) **done**
- MERIS in progress

R2014.0 Ocean Color Product and Algorithm Changes

$R_{rs}(\lambda)$	*calibration updates, ancillary data updates, improved land/water masking, terrain height, other minor fixes*
Ångstrom	
AOT	
Chlorophyll *a*	*standard chlor_a product now OCI algorithm (Hu et al. 2012) original OC3/OC4 product still being distributed as chl_ocx*
$K_d(490)$	*no change*
POC	*no change*
PIC	*updated algorithm and LUT*
CDOM_index	*remove product (redundant with new IOP suite)*
PAR	*consolidated algorithm, minor fixes*
iPAR	*MODIS-only, no change*
nFLH	*MODIS-only, flagging changes (allow negatives)*
IOPs	*added suite of inherent optical properties (Werdell et al. 2013)*

IOP Product Suite

Products

• a(λ)	*total absorption at all visible wavelengths*
• bb(λ)	*total backscatter at all visible wavelengths*
• aph(λ)	*absorption due to phytoplankton*
• adg(443)	*absorption due to gelb. & detritus at 443nm*
• Sdg	*exponential spectral slope for adg*
• bbp(443)	*particle backscattering at 443nm*
• Sbp	*power-law spectral slope for bbp*
• uncertainties	*uncertainties in adg, aph, bbp at 443nm*

SeaWiFS	λ = 412, 443, 490, 510, 555, 670
MODIS	λ = 412, 443, 469, 488, 531, 547, 555, 645, 667, 678
VIIRS	λ = 410, 443, 486, 551, 671

Rationale

provides sufficient information to compute full spectral component absorption and scattering coefficients and uncertainties

Action for Team Members

Algorithm POCs please review and revise existing algorithm description documents for all current standard products.

http://oceancolor.gsfc.nasa.gov/cms/atbd

$R_{rs}(\lambda)$	*Franz*
Chlorophyll *a*	*Werdell, Hu*
$K_d(490)$	*Werdell*
POC	*Stramski (Franz)*
PIC	*Balch*
PAR	*Frouin*
iPAR	*Bailey (Franz)*
nFLH	*Westberry*
IOPs	*Werdell*
SST (11um)	*Minnett (Kilpatrick)*
SST (4um)	*Minnett (Kilpatrick)*

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External Partners
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Algorithm Descriptions

The Ocean Biology Processing Group (OBPG) produces and distributes a standard suite of ocean color products for all compatible sensors at Level-2 and Level-3, plus sea surface temperature (SST) products from MODIS. The OBPG also produces a suite of Level-3 evaluation products. Descriptions and references for these standard and evaluation products are provided below.

Standard Ocean Color Products

Chlorophyll *a* (chlor_a; mg m^{-3})
The concentration of the photosynthetic pigment chlorophyll *a*.

Diffuse attenuation coefficient for downwelling irradiance at 490 nm (Kd_490; m^{-1})
The diffuse attenuation coefficient for downwelling irradiance over the first optical attenuation layer.

Inherent Optical Properties (IOPs; m^{-1})
The spectral marine absorption and backscattering coefficients of water column constituents.

Particulate Organic Carbon (POC; mg m^{-3})
The concentration of particulate organic carbon.

Particulate Inorganic Carbon (PIC; mol m^{-3})
The concentration of particulate inorganic carbon.

Photosynthetically Available Radiation (PAR; Einstein m^{-2} d^{-1})
Daily mean photosynthetically available radiation (PAR) at the ocean surface.

Instantaneous Photosynthetically Available Radiation (iPAR; Einstein m^{-2} s^{-1})
PAR the ocean surface at the time of the satellite observation. MODIS only.

Normalized Fluorescence Line Height (nFLH; mW cm^{-2} µm^{-1} sr^{-1})
Relative measure of water-leaving radiance associated with chlorophyll fluorescence. MODIS only.

Remote Sensing Reflectance (Rrs; sr^{-1})
The at-surface spectral remote-sensing reflectances observed by the satellite instrument after atmospheric correction. The aerosol optical thickness and Ångstrom data products are also described.

Standard Sea Surface Temperature Products

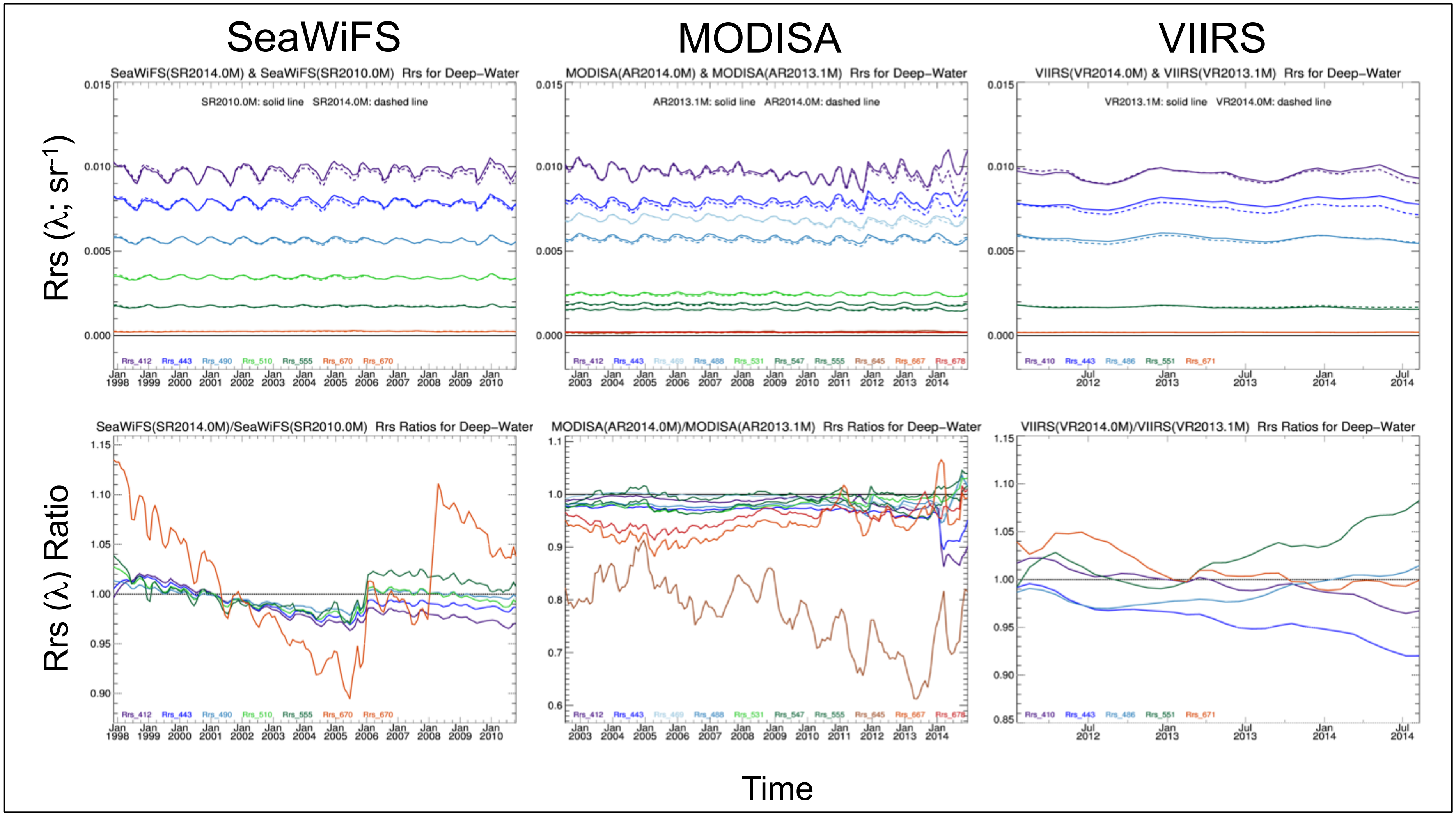
11 µm Sea Surface Temperature (SST; °C)
Sea surface temperature derived from long-wave (11-12 µm) thermal radiation. MODIS only.

4 µm Sea Surface Temperature (SST4; °C)
Sea surface temperature derived from short-wave (3-4 µm) thermal radiation. MODIS only.

R2014.0 Instrument VNIR Calibration Changes

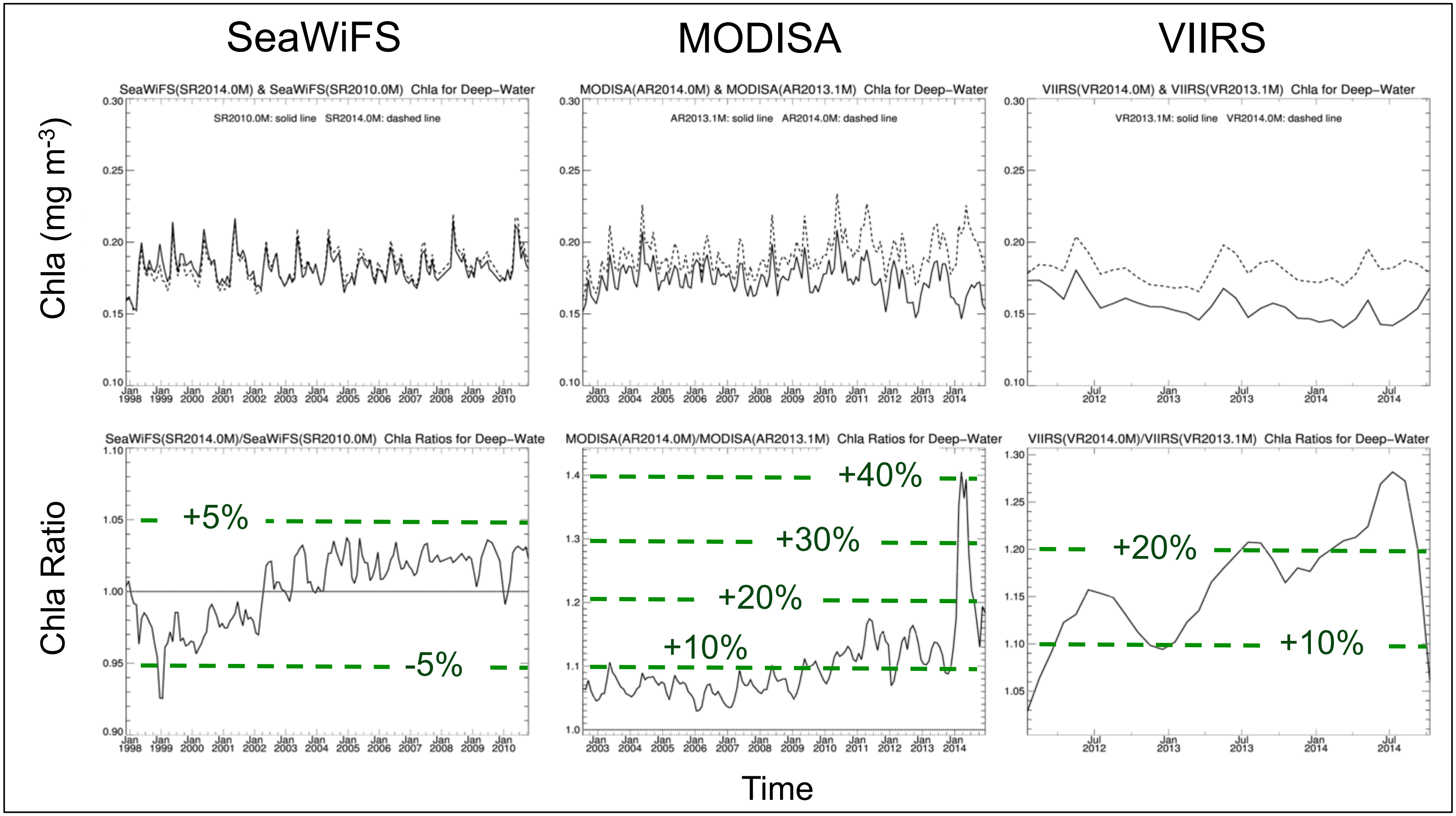
SeaWiFS	• *correcting dark offset changes at the sub-count level* • *correction for time-dependent change in system spectral response* • *Patt et al. (in prep), Eplee et al. (in prep)*
MODISA	• *updated temporal calibration from MCST (V6.1.35.17_OC2)* • *updated temporal corrections to response versus scan angle* • *Meister and Franz 2014.*
MODIST	• *updated temporal calibration from MCST (V6.1.20.16)* • *updated temporal corrections for response versus scan angle and polarization sensitivity (crosscal to SeaWiFS and MODISA)*
VIIRS	• *first use of lunar calibration trends to track temporal degradation of VIIRS (lunar calibration is used to correct more frequent but more uncertain solar calibration trends).* • *correction of the lunar calibration trends for time-dependent changes in spectral response of the primary mirror.* • *correction of solar calibration trends for a solar unit vector error in the source data used for solar calibration analysis, and improved solar diffuser stability corrections.* • *additional statistical correction for detector striping.* • *Eplee et al. 2015*

Reprocessing Impact on OC Time-Series



Rrs time-series comparison for global mean deep-water (> 1000m) between previous reprocessing (solid lines) and R2014.0 reprocessing (dashed lines). Bottom row shows Rrs ratio of like bands. Changes to the trends are significant for all sensors.

Reprocessing Impact on OC Time-Series

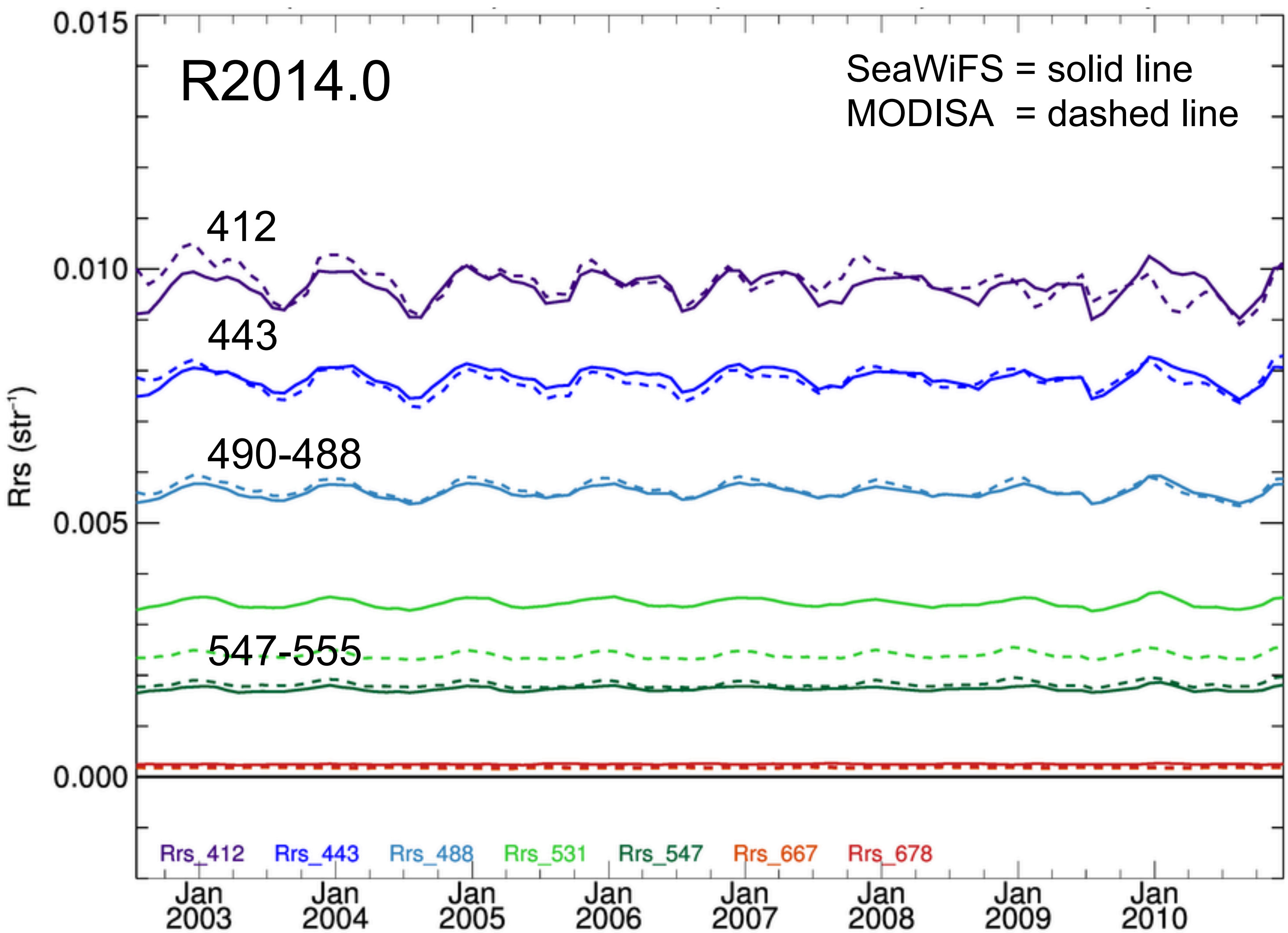


Chla time-series comparison for global mean deep-water between previous reprocessing (solid lines) and R2014.0 reprocessing (dashed lines). Bottom row shows Chla ratio. Impact of the reprocessing is significant for all sensors.

OC Product Consistency

SeaWiFS & MODISA Rrs(λ) Deep-Water Time-Series

showing good agreement



Mean Ratio

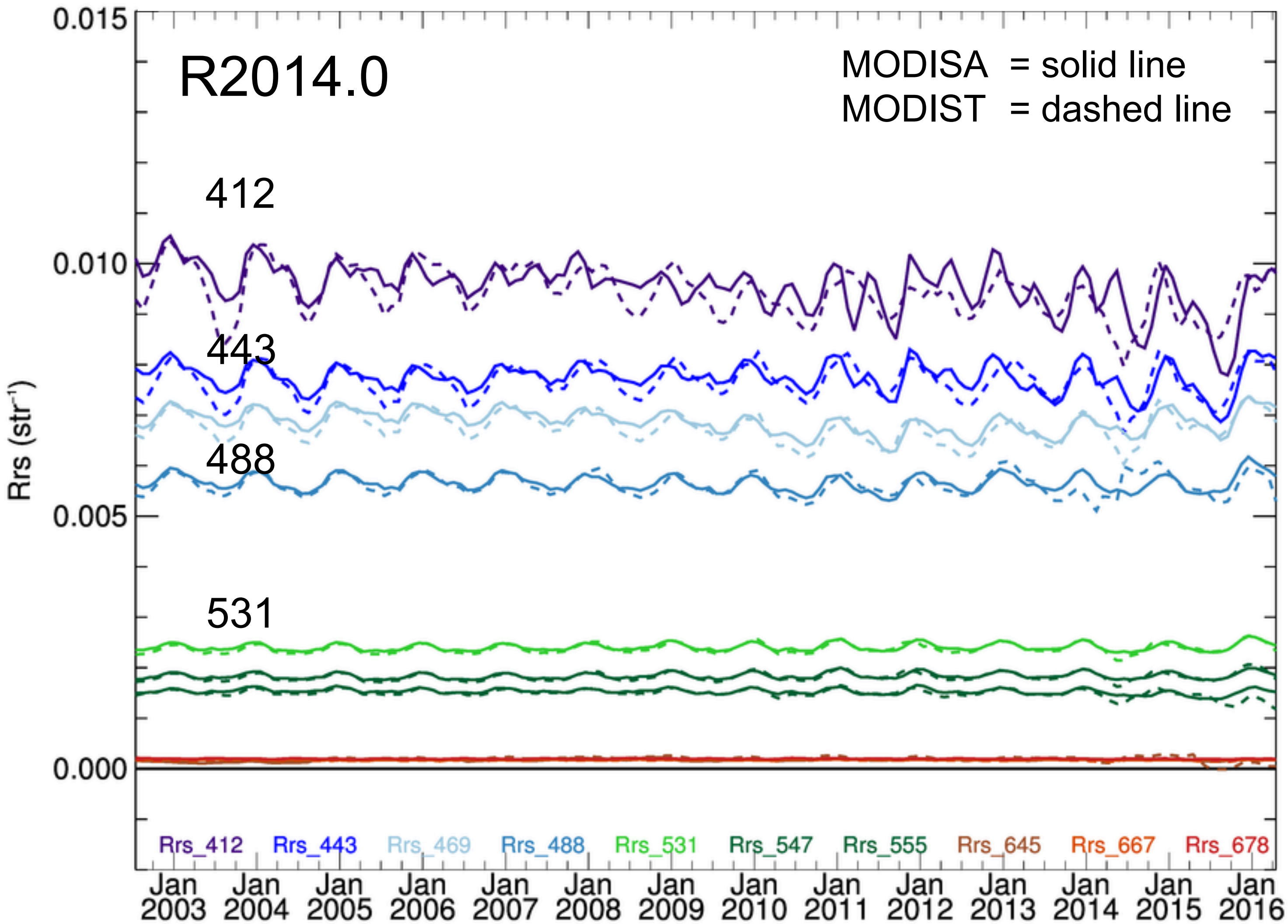
1.01

0.99

1.01

MODIST & MODISA Rrs(λ) Deep-Water Time-Series

showing "mostly" good agreement



Mean Ratio

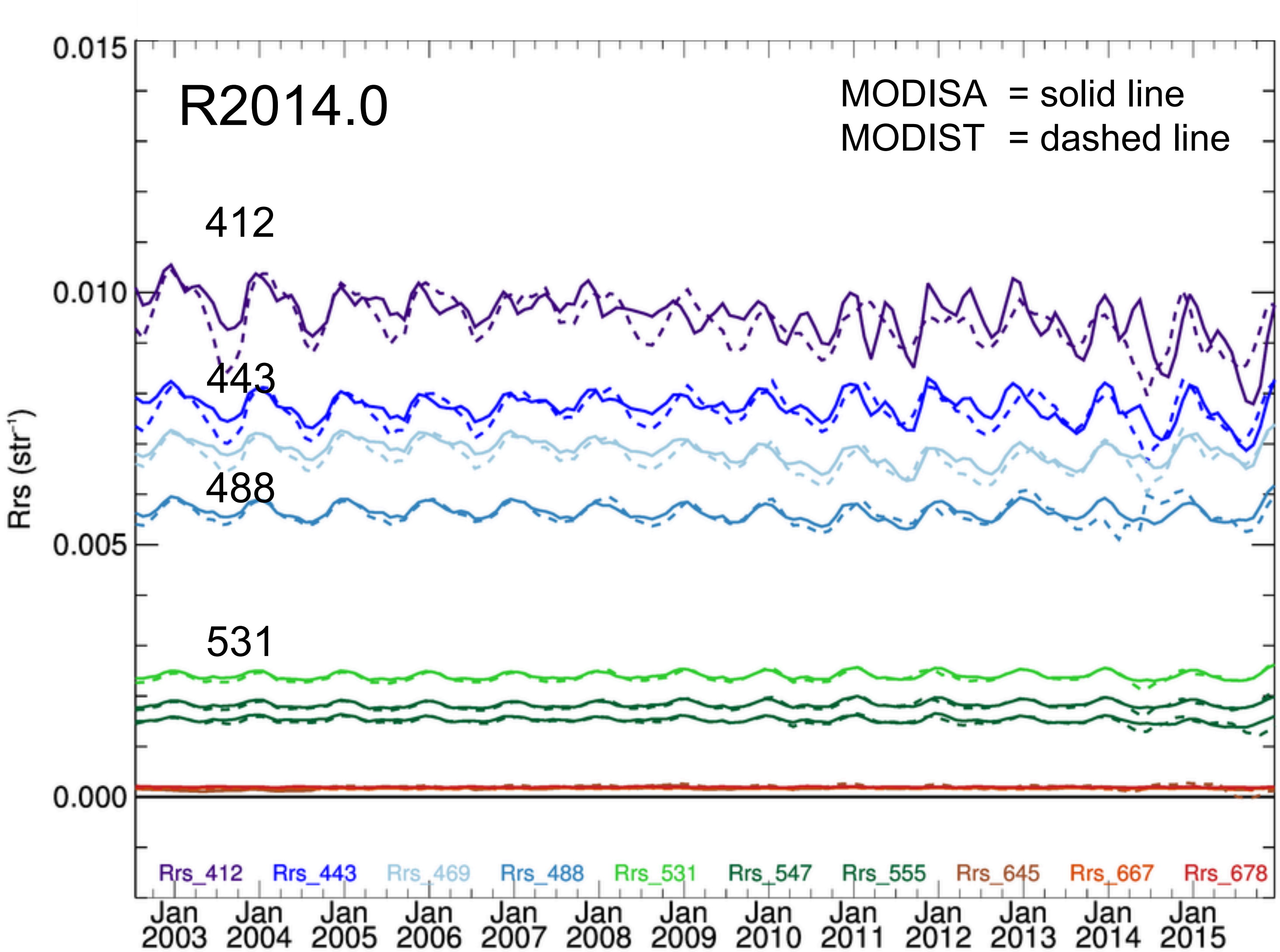
0.99

0.99

0.99

MODIST & MODISA Rrs(λ) Deep-Water Time-Series

showing "mostly" good agreement



Mean Ratio

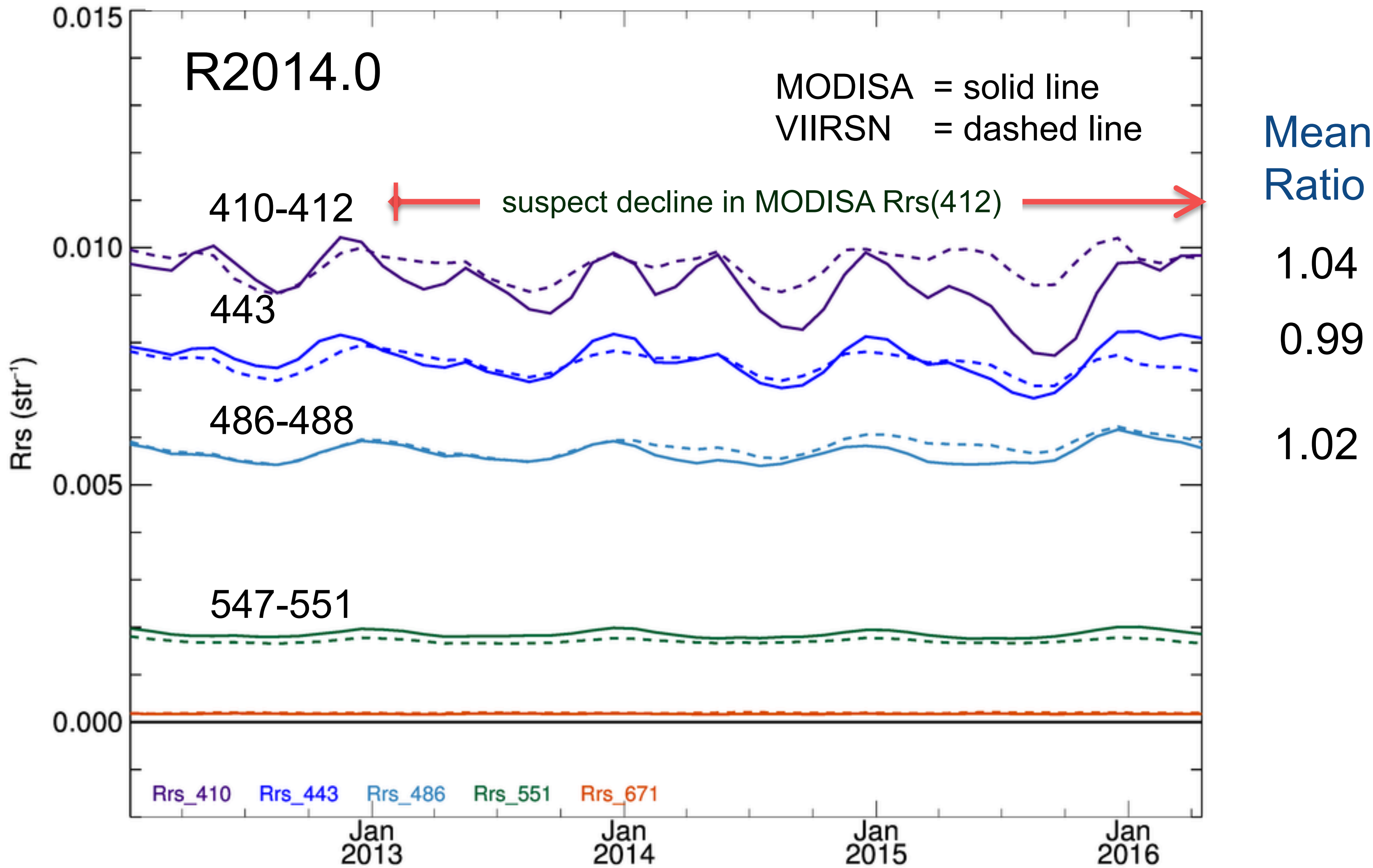
0.98

0.98

0.99

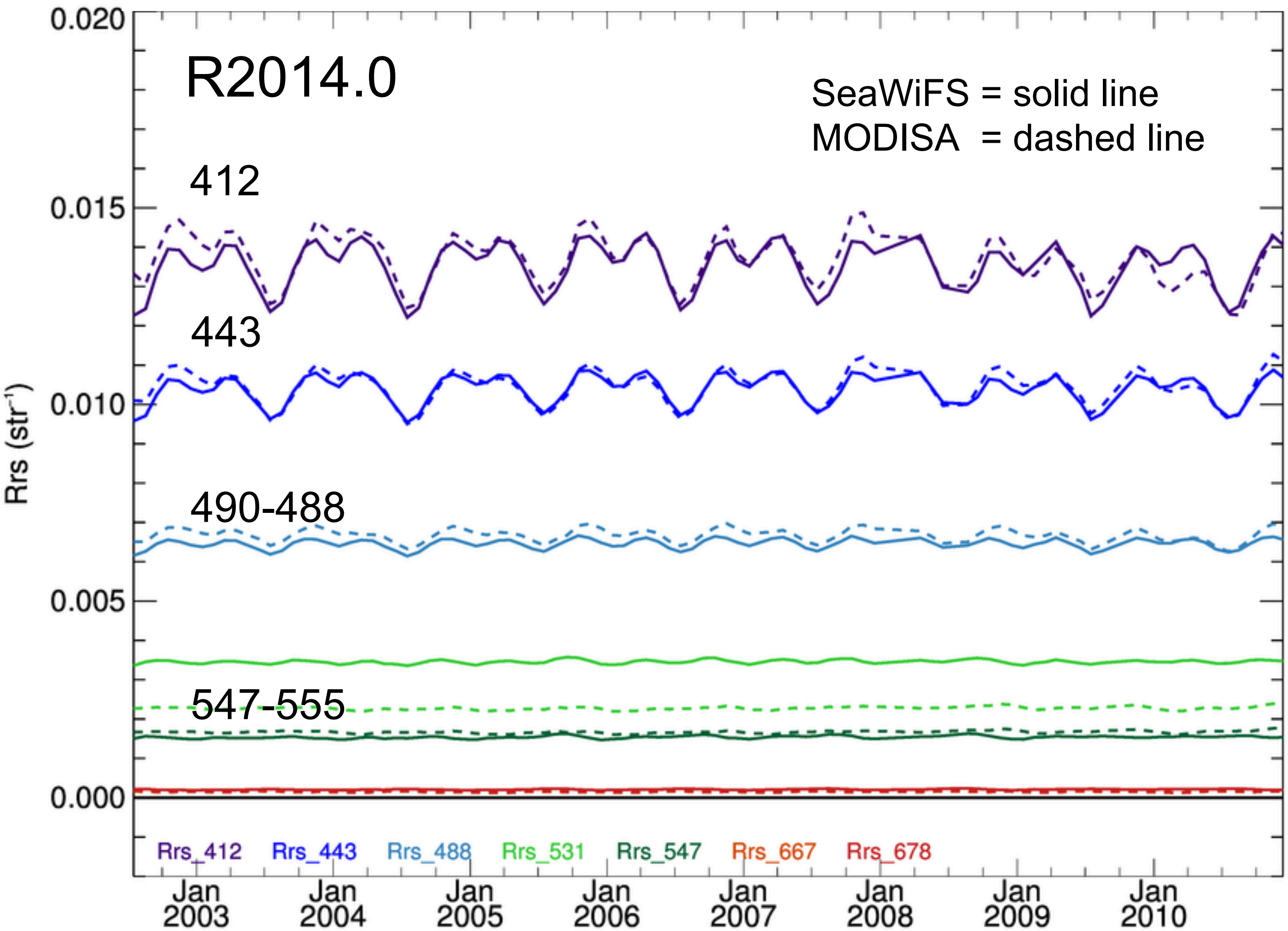
MODISA & VIIRS Rrs(λ) Deep-Water Time-Series

showing “good” agreement



SeaWiFS & MODISA Rrs(λ) Clear-Water Time-Series

showing “good” agreement



Mean Ratio

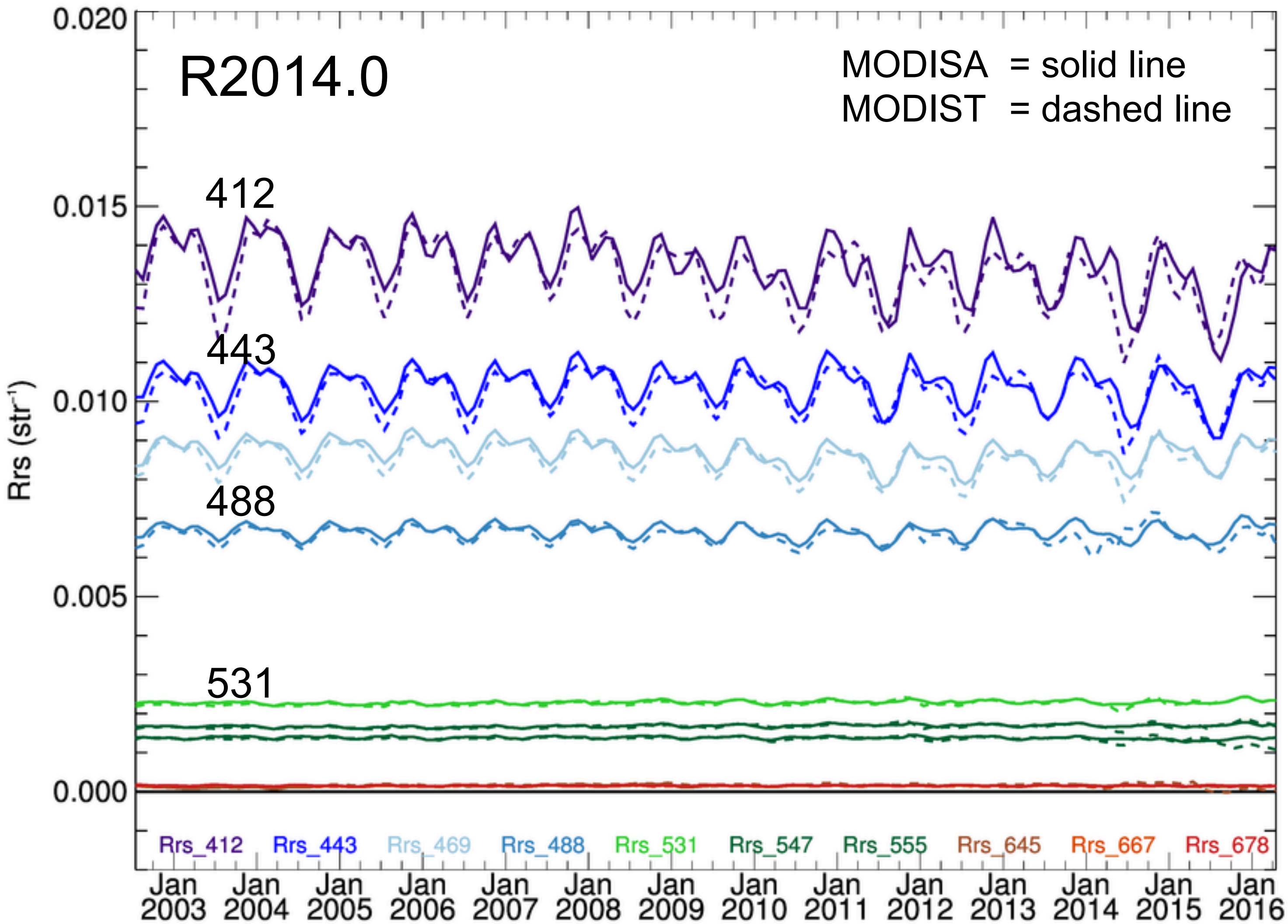
1.01

1.01

1.03

MODIST & MODISA Rrs(λ) Clear-Water Time-Series

showing "good" agreement



Mean Ratio

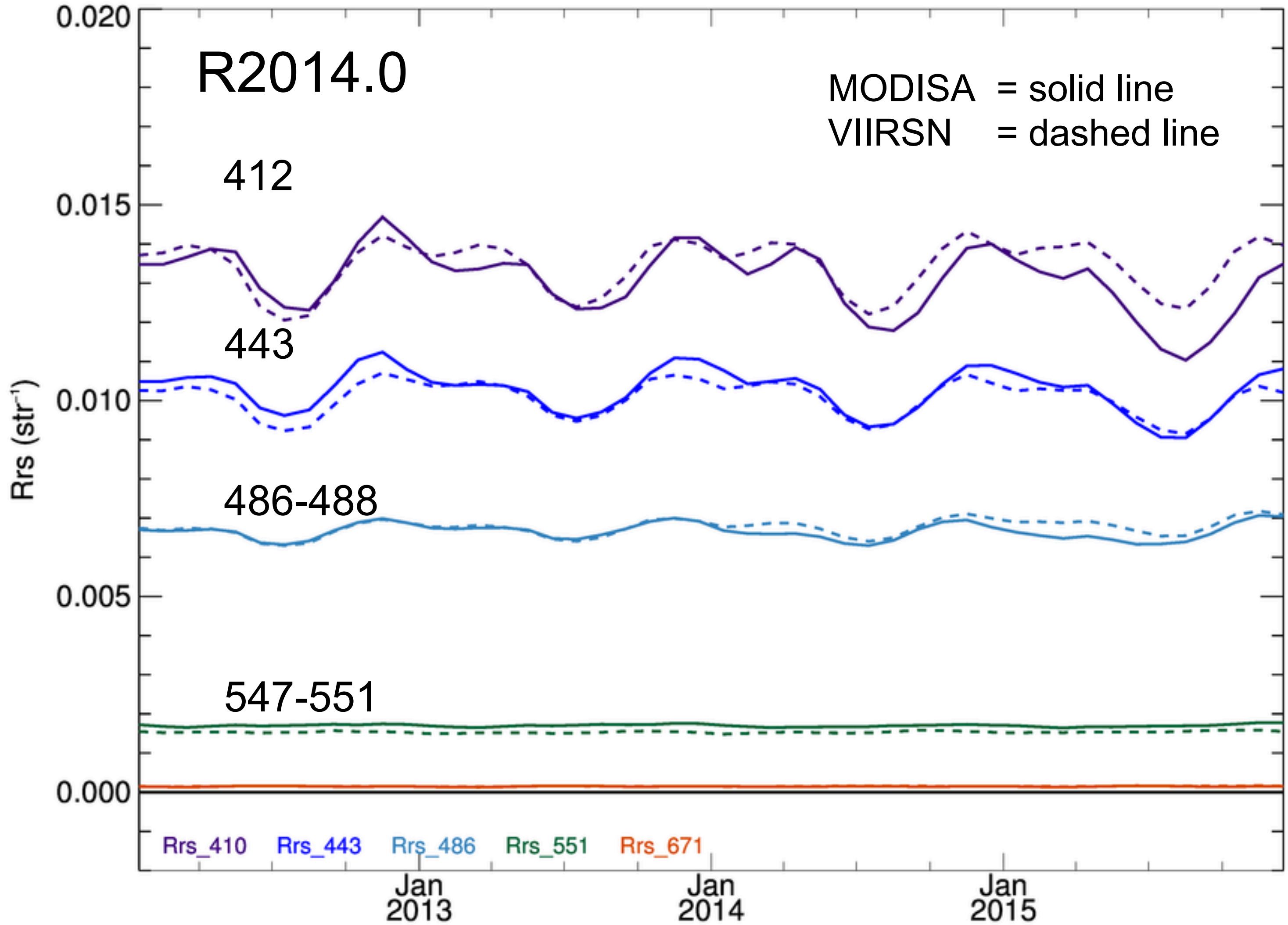
0.98

0.98

0.99

MODISA & VIIRS Rrs(λ) Clear-Water Time-Series

showing "good" agreement



Mean Ratio

1.03

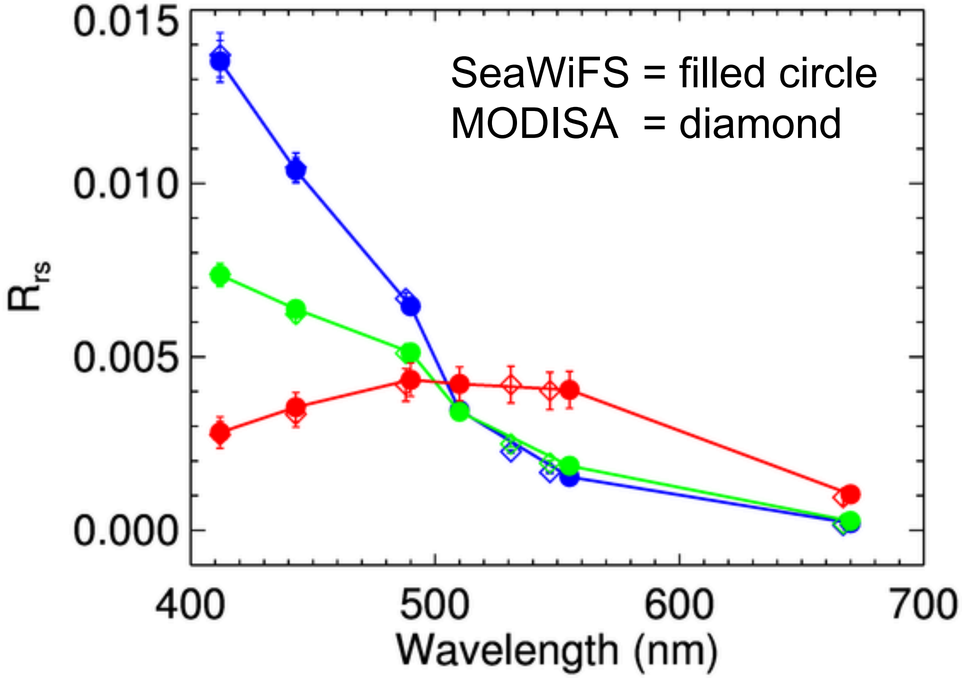
0.98

1.02

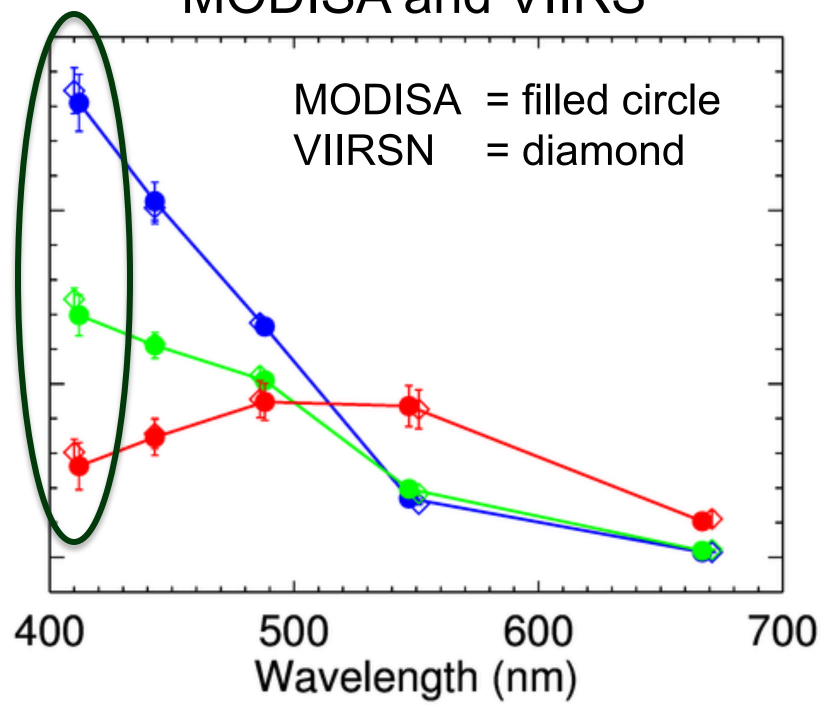
Rrs(λ) Spectral Comparison

common mission mean by water type

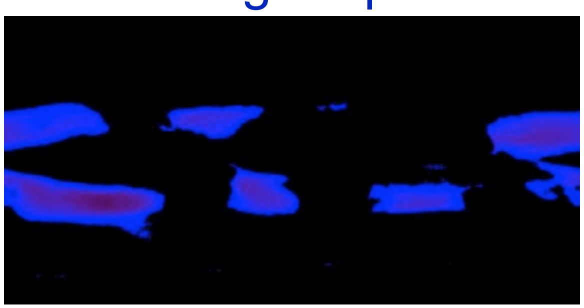
SeaWiFS and MODISA



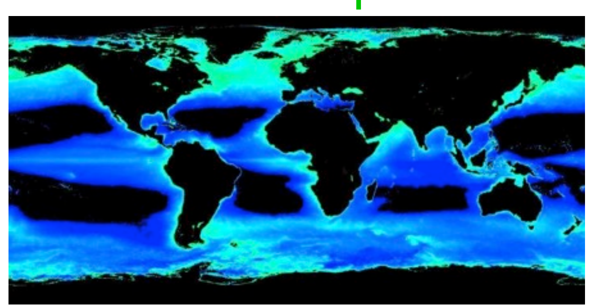
MODISA and VIIRS



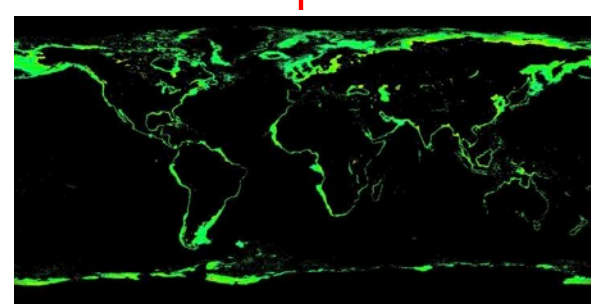
Oligotrophic



Mesotrophic



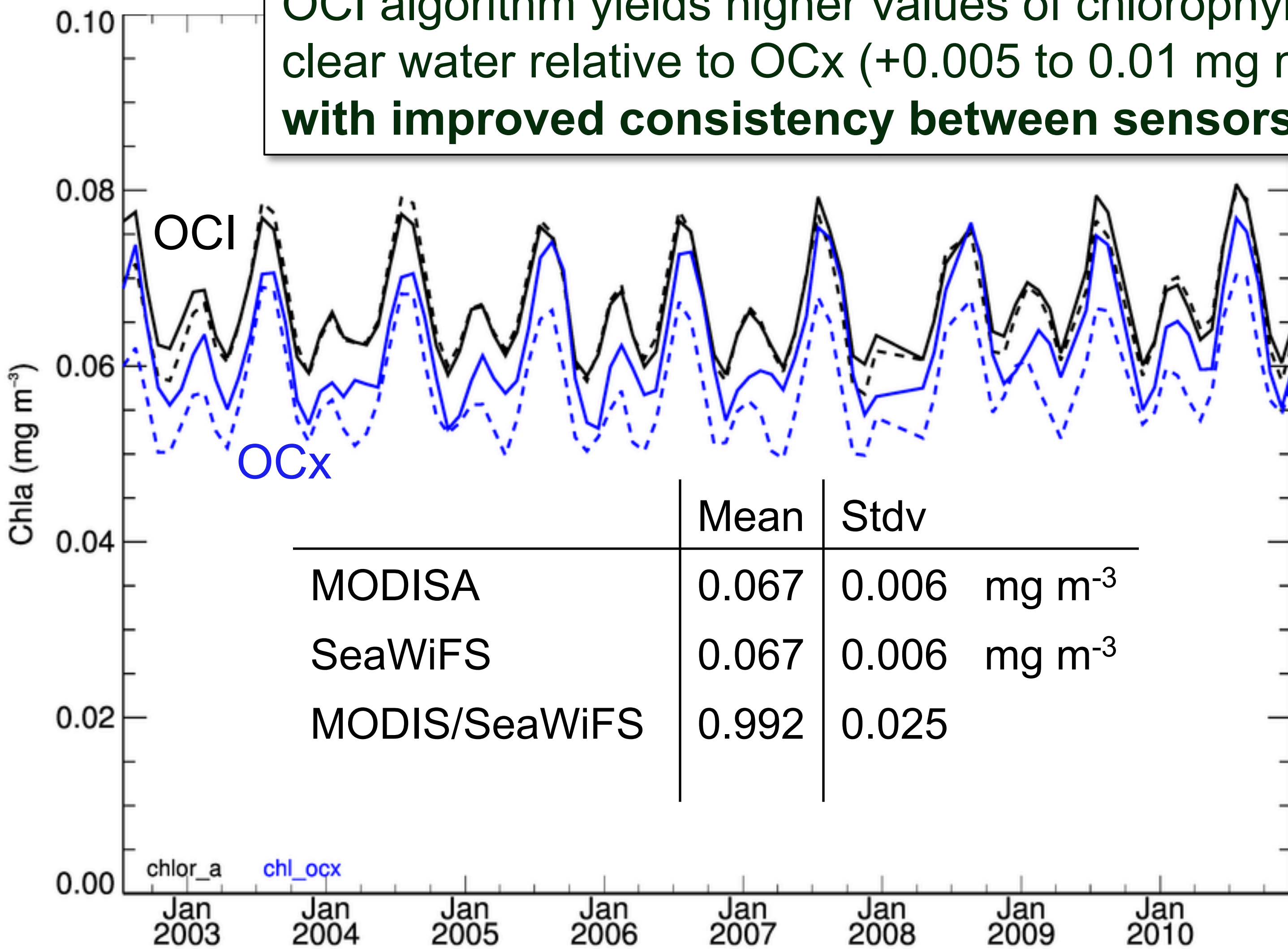
Eutrophic



SeaWiFS and MODISA R2014.0

Chlorophyll Clear-Water Time-Series

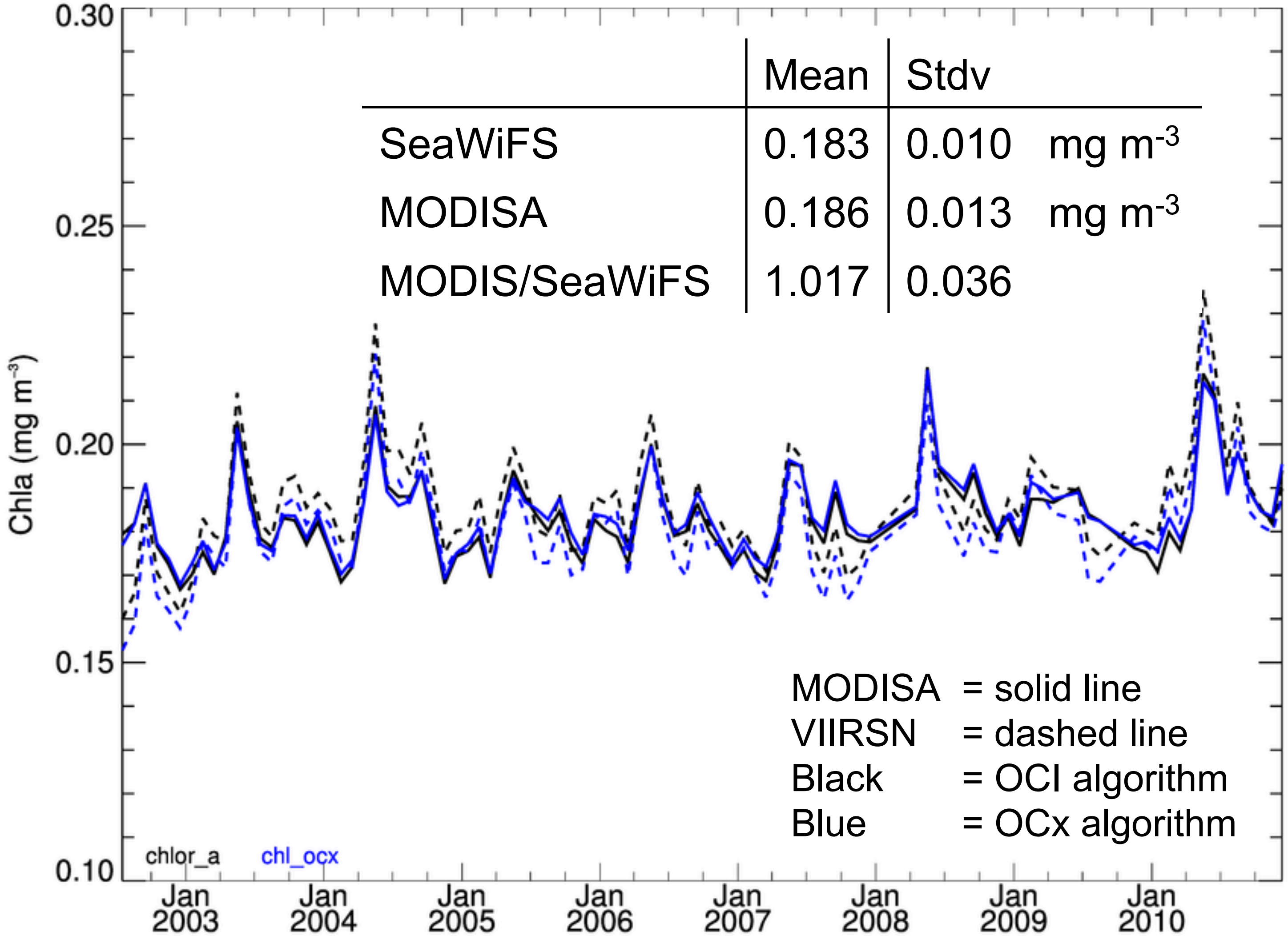
OCI algorithm yields higher values of chlorophyll in clear water relative to OCx (+0.005 to 0.01 mg m^{-3}), **with improved consistency between sensors**.



	Mean	Stdv	
MODISA	0.067	0.006	mg m^{-3}
SeaWiFS	0.067	0.006	mg m^{-3}
MODIS/SeaWiFS	0.992	0.025	

SeaWiFS and MODISA R2014.0

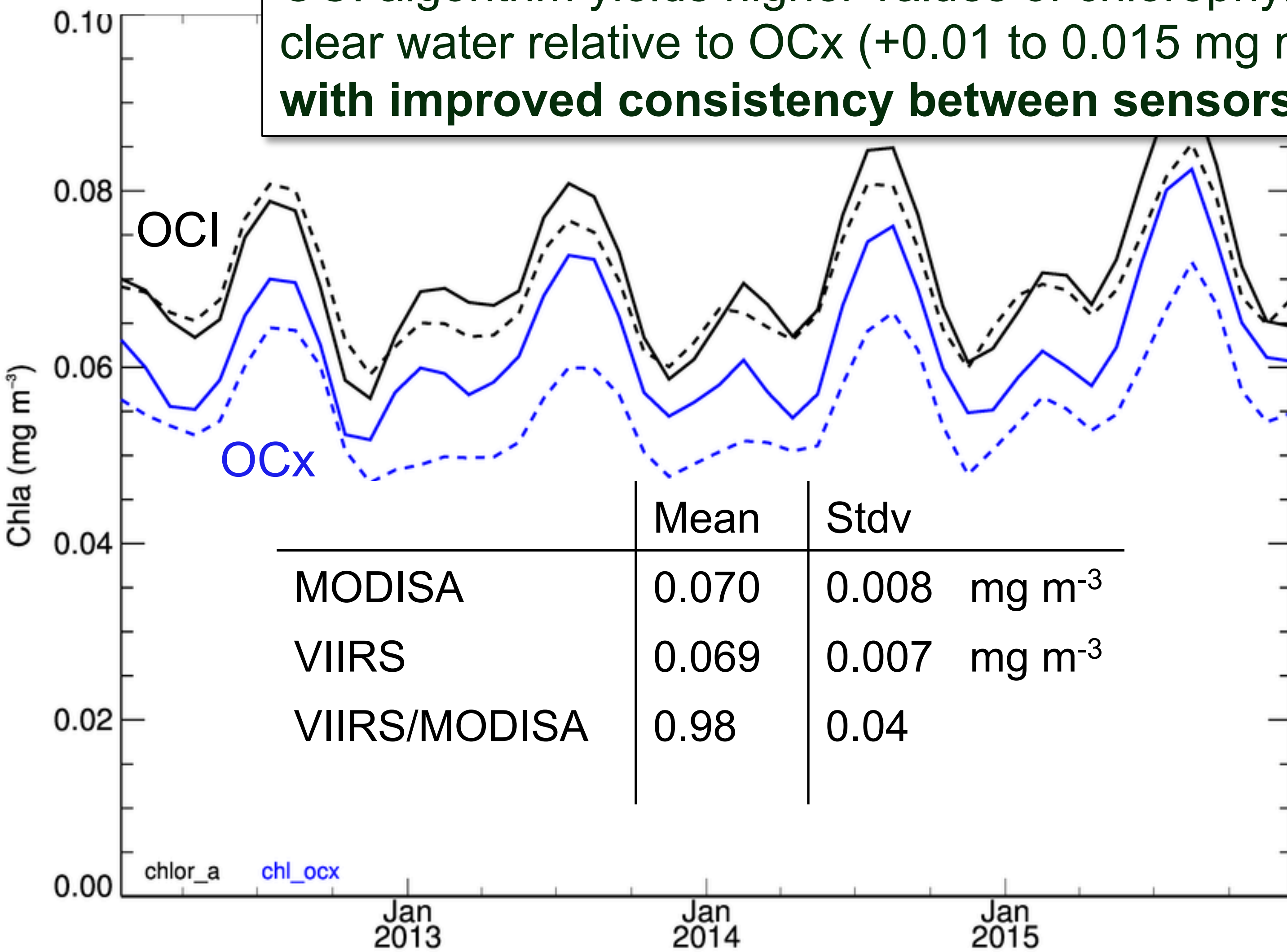
Chlorophyll Deep-Water Time-Series



MODISA and VIIRS R2014.0

Chlorophyll Clear-Water Time-Series

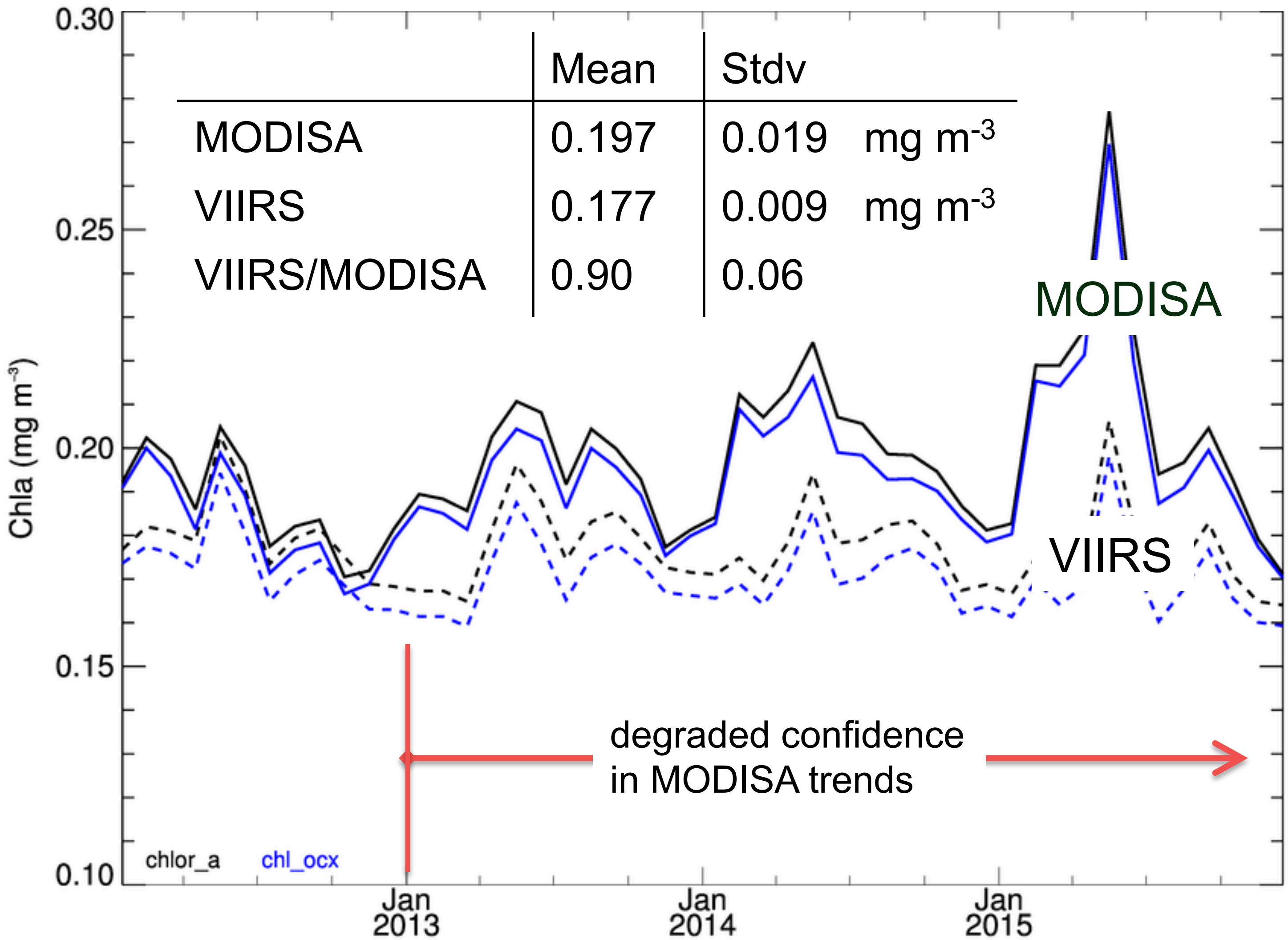
OCI algorithm yields higher values of chlorophyll in clear water relative to OCx (+0.01 to 0.015 mg m^{-3}), **with improved consistency between sensors**.



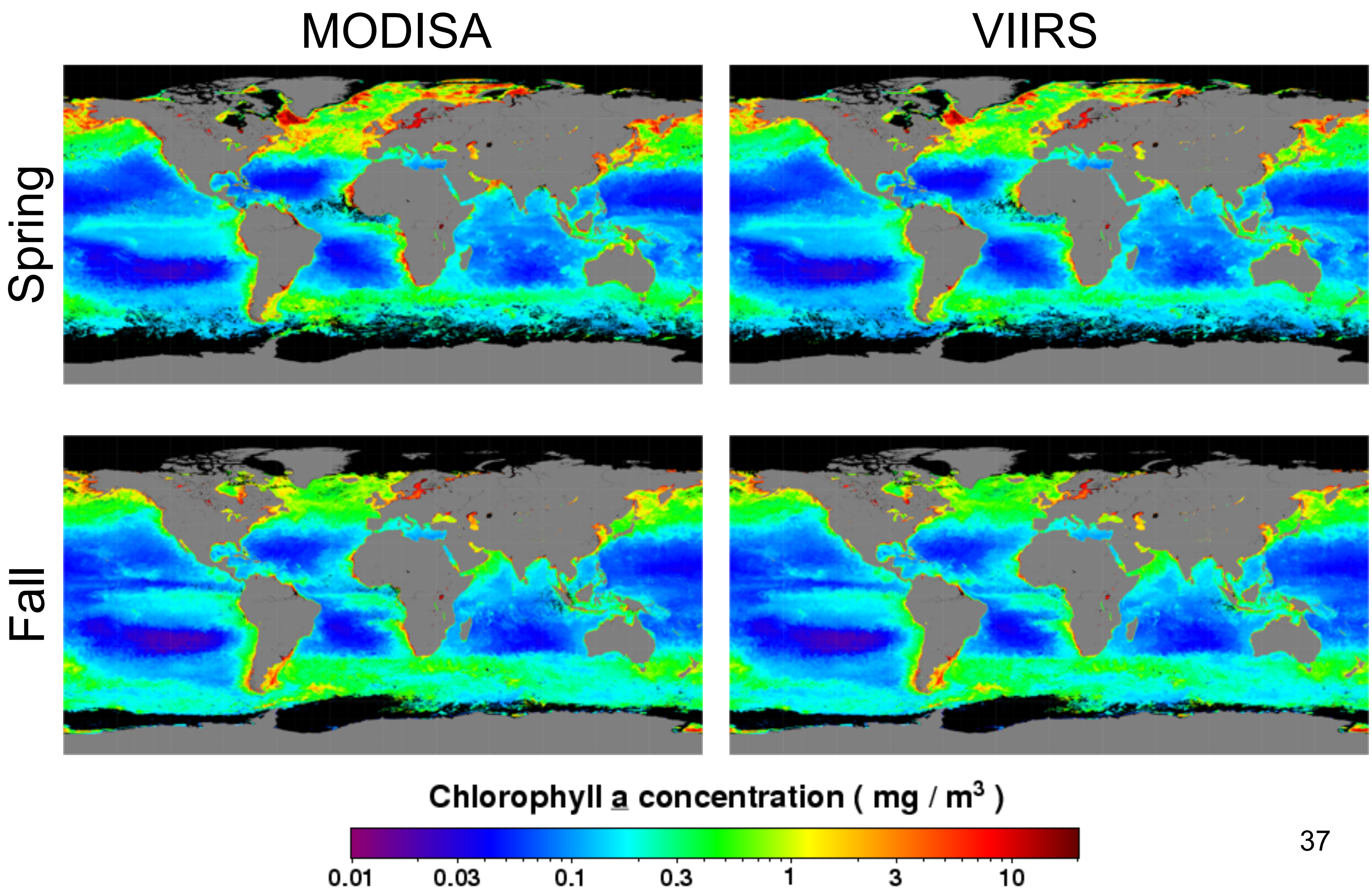
	Mean	Stdv	
MODISA	0.070	0.008	mg m^{-3}
VIIRS	0.069	0.007	mg m^{-3}
VIIRS/MODISA	0.98	0.04	

MODISA and VIIRS R2014.0

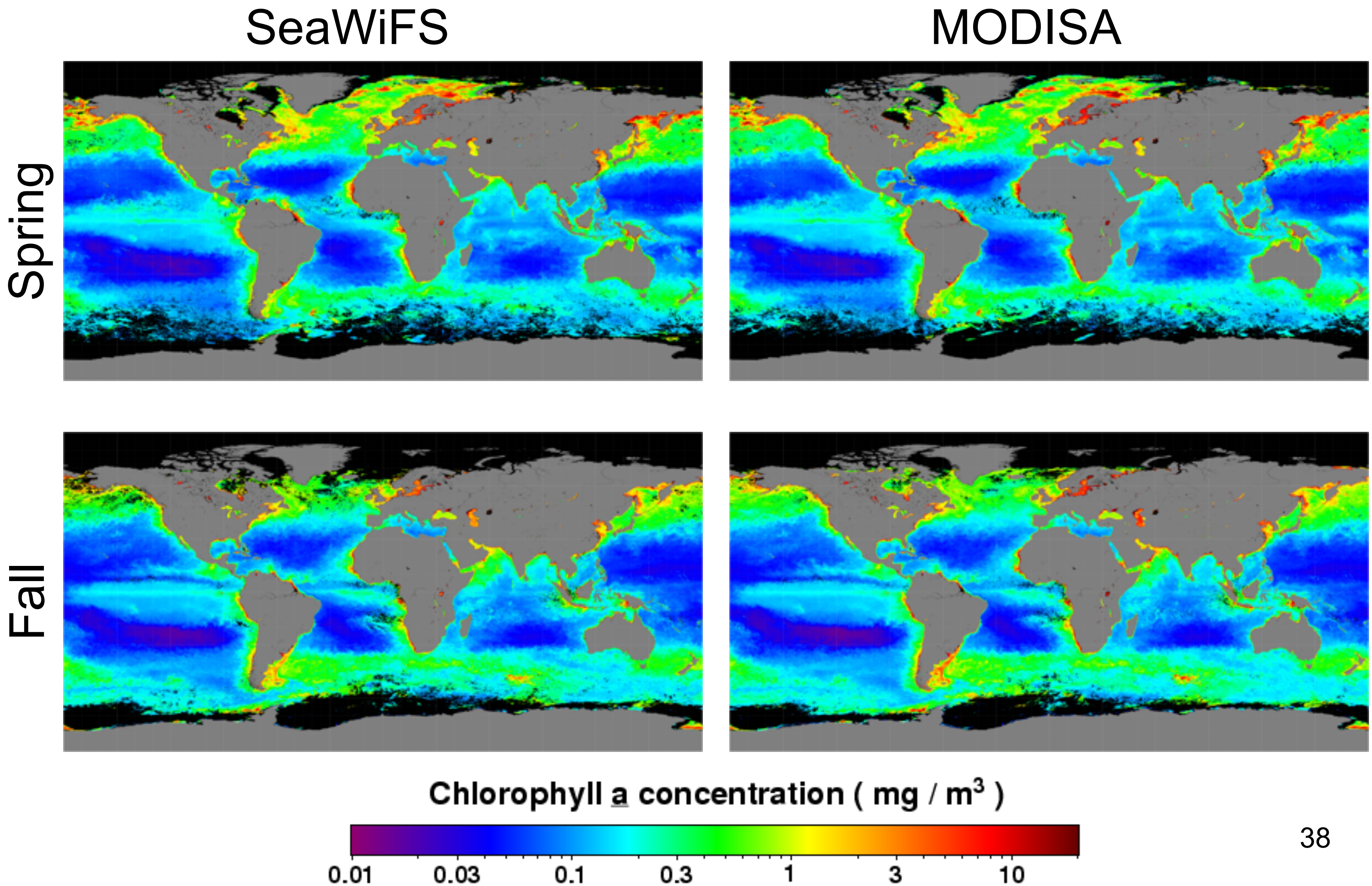
Chlorophyll Deep-Water Time-Series



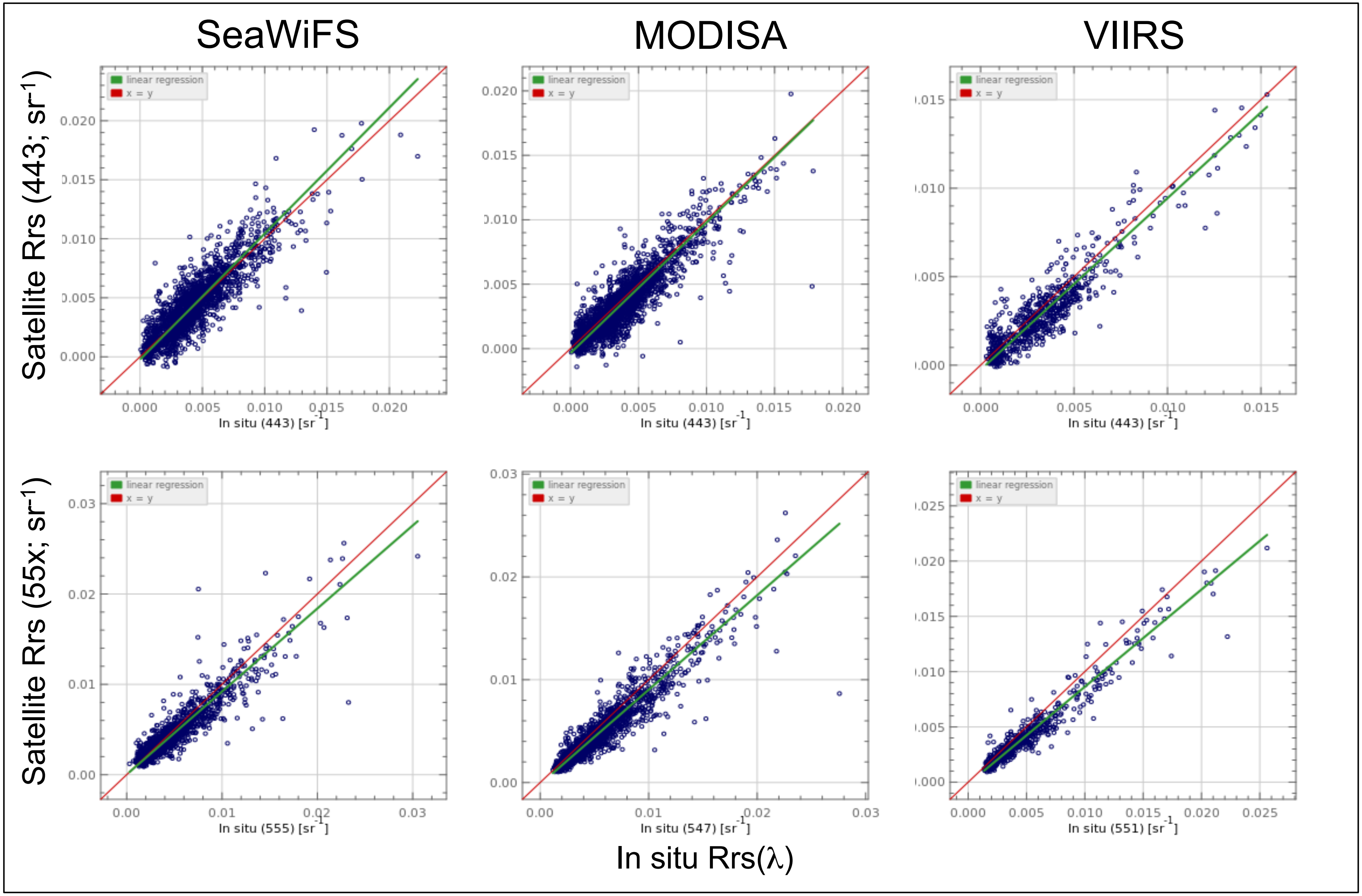
Seasonal Chlorophyll Comparison (2015)



Seasonal Chlorophyll Comparison (2005)



OC Product Validation



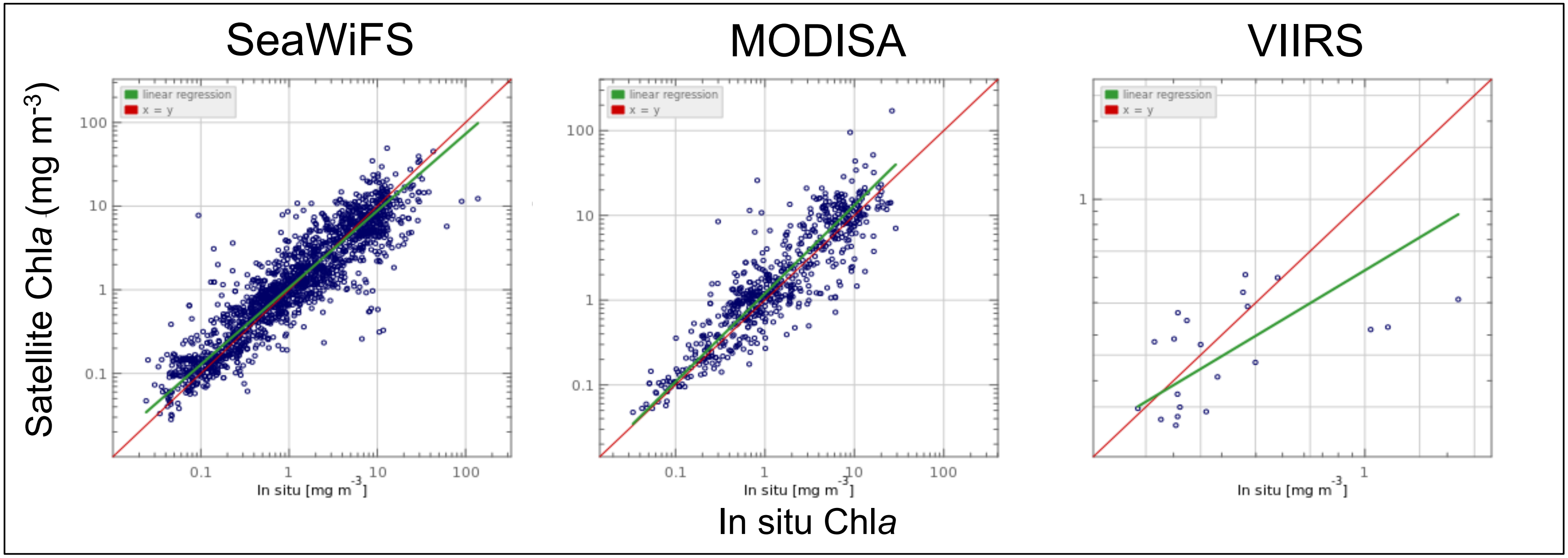
Comparison between R2014.0 satellite retrievals and in situ measurements for Rrs at 443nm and near 550nm. Match-up is for all available in situ data from SeaBASS and AERONET-OC.

	PRODUCT	COUNT	SLOPE	INT (sr^{-1})	R^2	MED RATIO	APD (%)	RMSE (sr^{-1})
SeaWiFS	Rrs 412	1681	1.10	-0.00067	0.74	0.92	28.0	0.00170
	Rrs 443	1930	1.07	-0.00024	0.77	1.00	20.2	0.00134
	Rrs 490	1534	0.91	0.00003	0.82	0.92	15.9	0.00122
	Rrs 510	785	0.95	-0.00004	0.84	0.93	16.0	0.00102
	Rrs 555	1684	0.92	0.00002	0.86	0.92	15.0	0.00128
	Rrs 670	1288	0.97	-0.00009	0.76	0.86	31.7	0.00050
MODISA	Rrs 412	2189	1.02	-0.00077	0.69	0.79	37.4	0.00163
	Rrs 443	2350	1.01	-0.00035	0.81	0.92	19.6	0.00117
	Rrs 488	1987	0.89	-0.00021	0.89	0.85	18.7	0.00129
	Rrs 531	780	0.90	-0.00022	0.88	0.87	16.7	0.00146
	Rrs 547	1959	0.92	-0.00016	0.89	0.89	14.2	0.00128
	Rrs 667	1789	0.99	-0.00017	0.79	0.78	33.0	0.00049
	Rrs 678	465	1.16	-0.00034	0.82	0.76	34.1	0.00046
VIIRS	Rrs 410	693	0.96	-0.00044	0.71	0.76	38.9	0.00134
	Rrs 443	697	0.97	-0.00026	0.85	0.85	26.5	0.00100
	Rrs 486	697	0.87	-0.00019	0.93	0.81	23.5	0.00120
	Rrs 551	692	0.88	-0.00016	0.94	0.84	18.6	0.00119
	Rrs 671	693	0.96	-0.00019	0.85	0.76	30.6	0.00048

Statistical analysis of Rrs(λ) match-ups between R2014.0 satellite retrievals and in situ measurements, for all available in situ match-ups from SeaBASS and AERONET-OC.

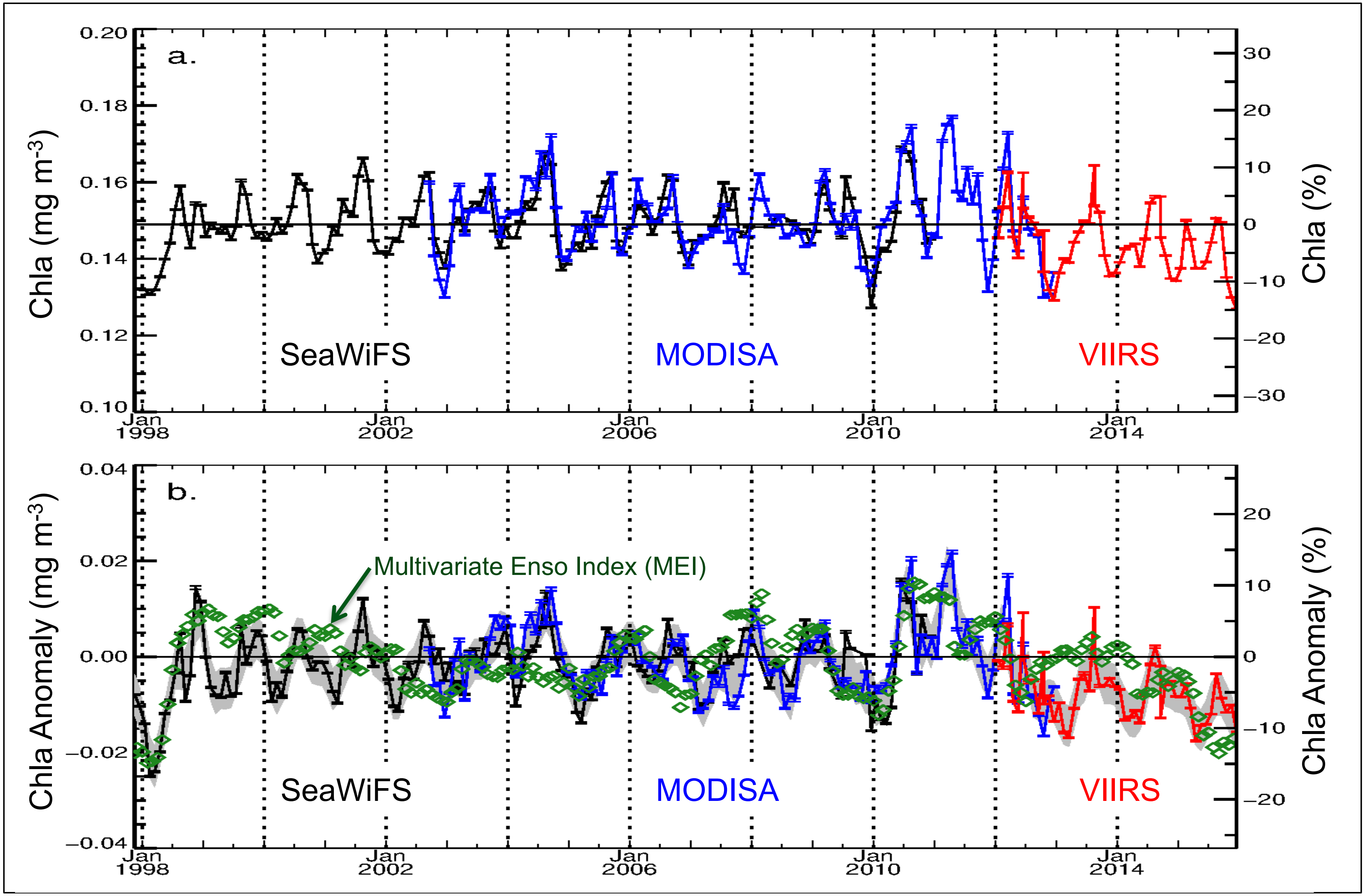
	PRODUCT	COUNT	SLOPE	INT (sr^{-1})	R^2	MED RATIO	APD (%)	RMSE (sr^{-1})
SeaWiFS	Rrs 412	241	0.99	0.00007	0.83	1.00	14.9	0.00167
	Rrs 443	418	0.98	0.00010	0.79	1.01	14.5	0.00124
	Rrs 490	427	0.97	-0.00004	0.63	0.97	12.3	0.00091
	Rrs 510	322	0.99	-0.00010	0.26	0.96	12.8	0.00066
	Rrs 555	245	0.90	0.00017	0.38	1.00	14.5	0.00048
	Rrs 670	89	0.91	0.00007	0.24	1.34	47.3	0.00015
MODISA	Rrs 412	154	1.01	-0.00037	0.86	0.97	12.0	0.00145
	Rrs 443	291	0.99	-0.00010	0.81	0.99	11.8	0.00107
	Rrs 488	304	0.99	-0.00026	0.65	0.96	9.3	0.00086
	Rrs 531	41	0.69	0.00060	0.38	0.96	8.6	0.00069
	Rrs 547	3	1.21	-0.00006	0.82	1.15	13.5	0.00035
	Rrs 667	239	1.53	-0.00008	0.05	0.97	37.5	0.00011
	Rrs 678	2	-0.04	0.00046	1.00	1.53	37.6	0.00016
VIIRS	Rrs 410	5	1.13	-0.00117	0.70	0.89	17.1	0.00192
	Rrs 443	5	1.00	0.00001	0.72	0.90	12.8	0.00127
	Rrs 486	5	1.17	-0.00090	0.39	0.97	13.8	0.00089
	Rrs 551	0						
	Rrs 671	3	0.97	-0.00016	0.58	0.56	57.0	0.00017

Statistical analysis of Rrs(λ) match-ups between R2014.0 satellite retrievals and in situ measurements, for all available in situ match-ups from SeaBASS, restricted to deep-water (> 1000m).



Chlorophyll a	PRODUCT	COUNT	SLOPE	INT (mg m^{-3})	R^2	MED RATIO	APD (%)	RMSE (mg m^{-3})
All	SeaWiFS	1739	0.92	0.02513	0.83	1.07	37.3	0.29030
All	MODISA	653	1.04	0.07814	0.80	1.19	40.7	0.30814
All	VIIRS	21	0.63	-0.27375	0.27	0.86	34.9	0.27166
Deep	SeaWiFS	363	0.83	-0.09787	0.74	1.01	32.4	0.24365
Deep	MODISA	113	0.87	-0.10674	0.85	0.97	22.5	0.19605
Deep	VIIRS	17	0.50	-0.37107	0.30	0.79	40.9	0.29676

Long-term (18-year) record of phytoplankton chlorophyll a for mid-latitude oceans (± 40^0), constructed from R2014.0



Ocean Break-out Agenda

June 8

Discussion		
4:20	Zhongping Lee	*Band averaged pure water properties*
4:30	Chuanmin Hu	*Chl-specific l2-flag to increase data volume?*
4:40	*Topics* • *questions for Ocean SIPS or OB.DAAC* • *product and algorithm documentation* • *new products?* • *product uncertainties* • *consistency across sensors, data merging from multiple sensors* • *interaction with PACE Science Team* • *organization of future meetings*	

New Products

Standard, Evaluation, and Test Products

- a **standard product** is one that the SIPS is committed to maintain, and the DAAC is committed to archive and distribute, at the ultimate discretion of Program Management

- an **evaluation product** is one that the SIPS/DAAC may produce and distribute, if resources allow, to support community assessment of a new product or alternative product algorithm

- a **test product** is one that the SIPS may produce to support the algorithm PI in implementation verification and product testing

in practice, OC standard products are made at Level-2 and Level-3, while eval products are made only at Level-3 (usually from Level-3 Rrs dailies).

Current Evaluation Products

- GSM IOP Algorithm
  - Chlorophyll, bbp(443), adg(443)

- QAA IOP Algorithm
  - a(443), adg(443), aph(443), bbp(443)

- Lee Euphotic depth
  - based on QAA IOPs

Product Lifecycle

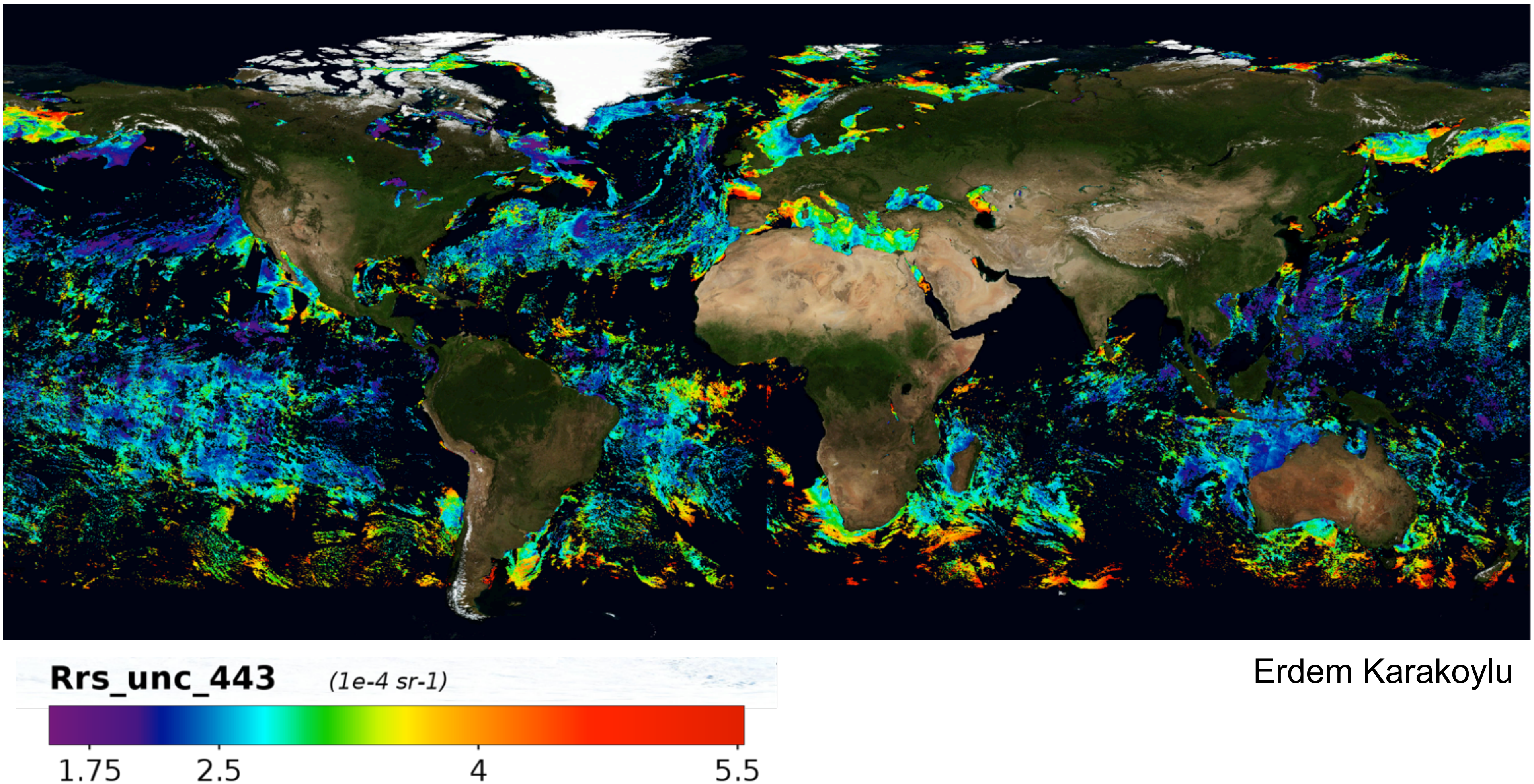
from concept to standard product

1. PI develops new algorithm or modification, demonstrates feasibility, perhaps publishes results.
2. If PI and Ocean Team Leader agree, PI works with SIPS to implement in NASA processing code and to develop a test plan for verification and large-scale testing.
3. If PI is satisfied with implementation tests, and SIPS confirms that **required computing resources are available**, evaluation products and documentation will be produced and distributed, and the algorithm will be incorporated into SeaDAS.
   a. PI works with SIPS to develop or update the Product Description Document (to be hosted under “evaluation products”).
   b. SIPS/DAAC begins production and distribution of product
   c. PI performs assessment of results (validation, global dist., trends)
4. Before the next mission reprocessing opportunity, PI/SIPS/DAAC and Program Management review the performance evaluation, documentation, and appropriateness for standard production.

Uncertainties

Rrs(λ) Uncertainty

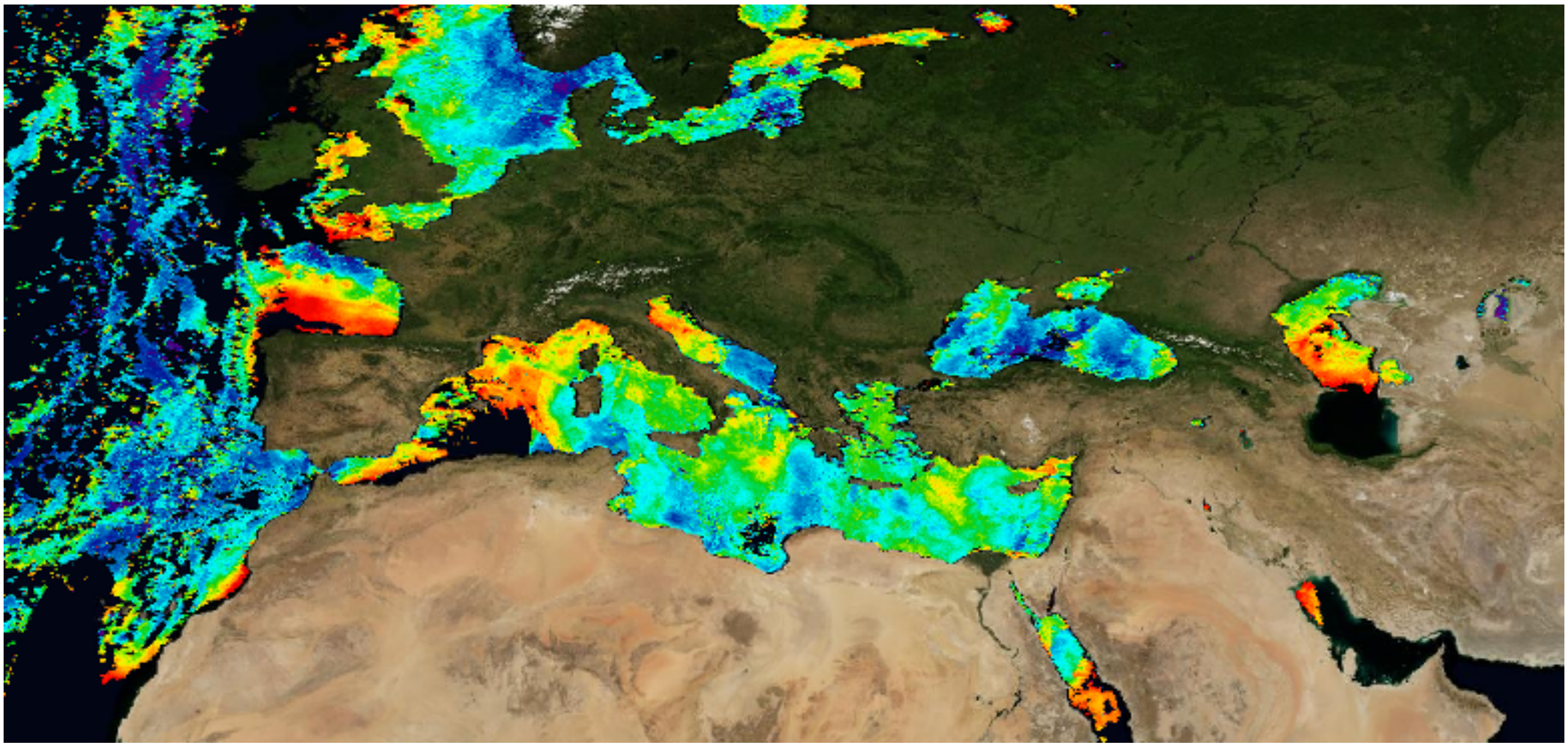
Using instrument noise model propagated through atmospheric correction via Monte Carlo simulation (SeaWiFS 4-day period shown, 1000 iterations)



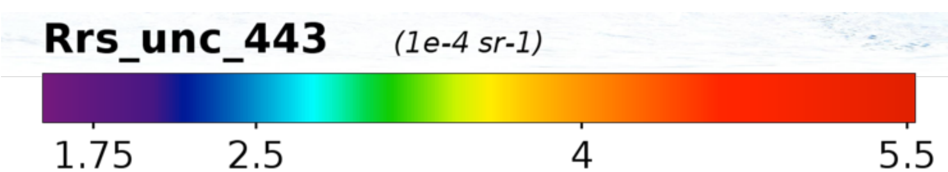
Erdem Karakoylu

Rrs(λ) Uncertainty

Using instrument noise model propagated through atmospheric correction via Monte Carlo simulation (SeaWiFS 4-day period shown, 1000 iterations)

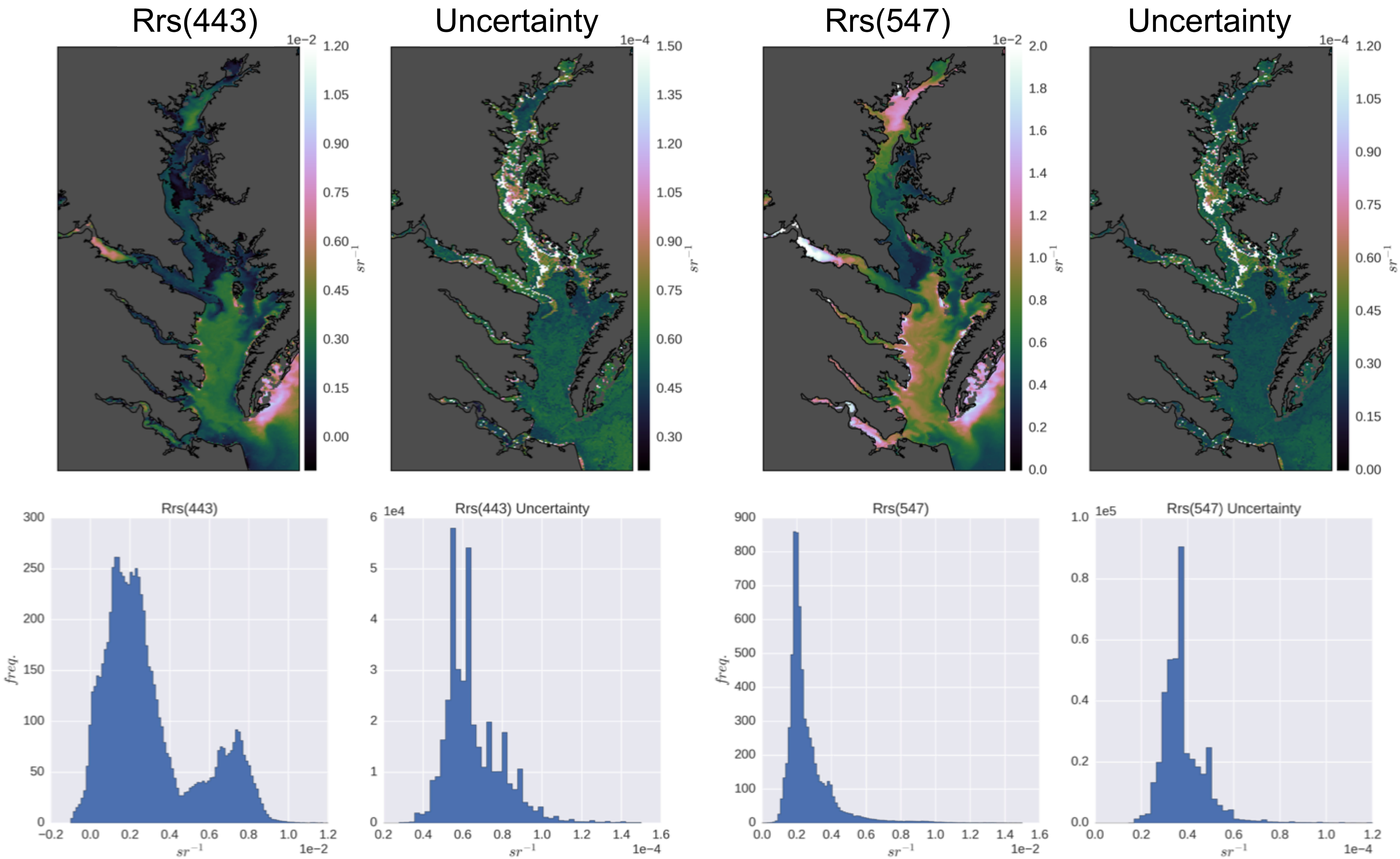


Erdem Karakoylu

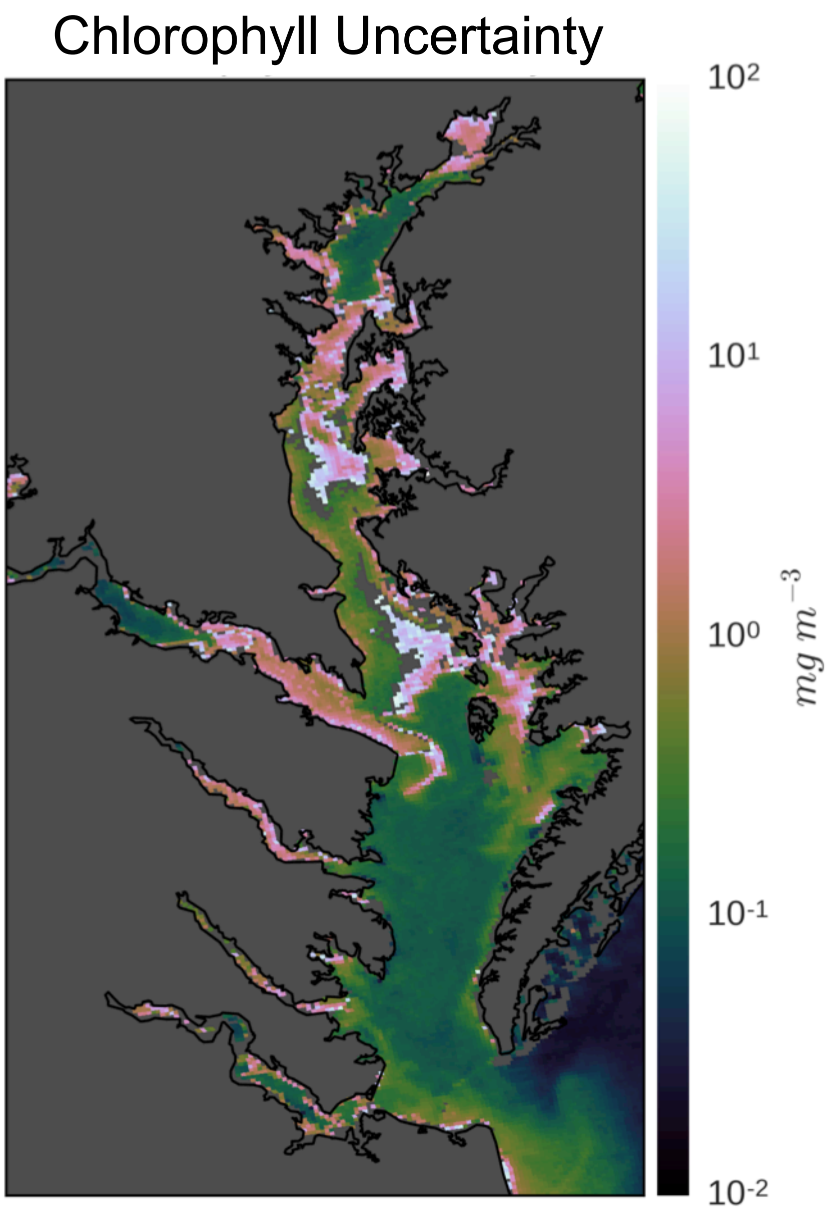


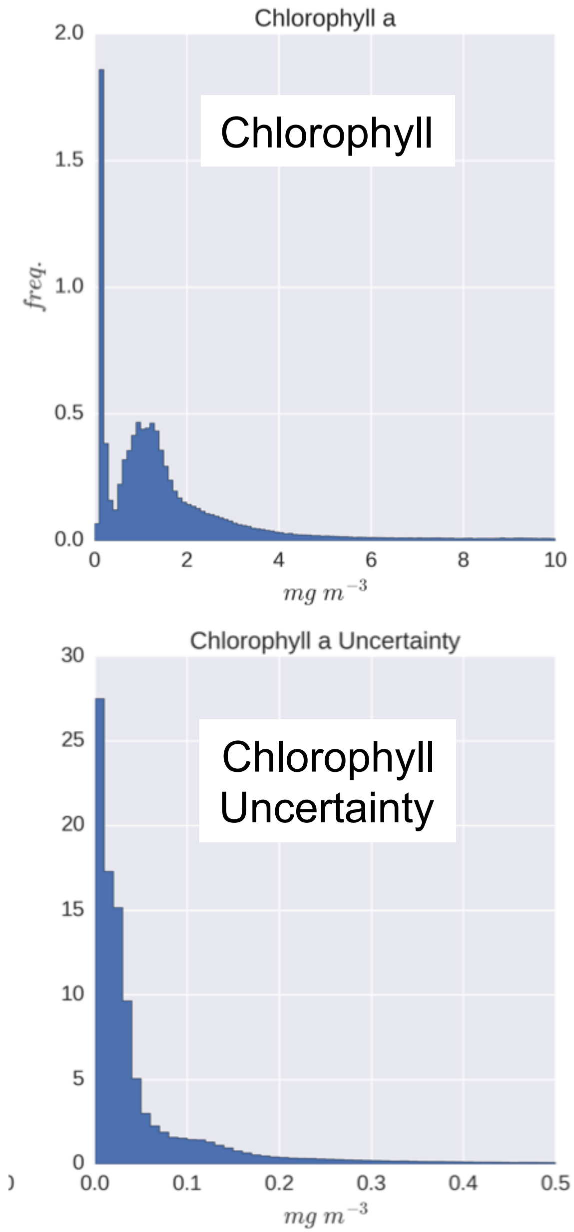
Developing per-pixel Rrs(λ) uncertainty estimates

instrument noise propagated through atmospheric correction via Monte Carlo simulation (MODIS-Aqua Ches. Bay, 1000 iterations)



Developing per-pixel chlorophyll uncertainty





Product Documentation

Product Documentation

- MODIS has historically required that every standard product have associated with it an Algorithm Theoretical Basis Document (ATBD)
- The original MODIS ATBDs are extremely out of date and in many cases they are not relevant to current standard products
- This is largely due to the fact that the MODIS processing was awarded to the NASA OBPG in 2004 with the mandate to adopt the SeaWiFS heritage processing, as documented in SeaWiFS TMs
- It is also the case that the ocean algorithms are predominantly sensor-independent, evolved from broad community contributions
- To satisfy NASA Program Management and better serve the research community, we need to establish a new set of product documentation for the current standard product suite of MODIS & VIIRS, and maintain that level of documentation going forward
- To that end, Ocean SIPS is developing a set of online documents that can be easily updated and will include dynamic links to ensure that implementation and validation information remains current

Product and Algorithm Description Document

standardized elements

- Product Summary
  - defines what it is and what it's for
- Algorithm Description
  - as detailed as necessary to ensure full traceability to algorithm basis and heritage (e.g., links to published literature)
  - if applicable to multiple sensors, include any sensor-specific modifications required (e.g., adjustments for band passes)
  - algorithm failure conditions and associated product flags
- Implementation
  - how is the product distributed (product suite, file-types, encoding)
  - direct links to source code and/or software flow charts

Product and Algorithm Description Document
standardized elements

- Assessment
  - validation analyses (e.g., direct link to dynamic match-ups)
  - uncertainties
- References
  - links to previous ATBD(s) or TM(s), if relevant
  - links to published literature (DOIs)
- Product History
  - document version (date)
  - product change log

Product Description Documents

EARTHDATA Data Discovery DAACs Community Science Disciplines

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- Home
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Algorithm Descriptions

The Ocean Biology Processing Group (OBPG) produces and distributes a standard suit[e] products for all compatible sensors at Level-2 and Level-3, plus sea surface temperatur[e] MODIS. The OBPG also produces a suite of Level-3 evaluation products. Descriptions [...] these standard and evaluation products are provided below.

Standard Ocean Color Products

Chlorophyll *a* (chlor_a; mg m^{-3})

The concentration of the photosynthetic pigment chlorophyll *a*.

Diffuse attenuation coefficient for downwelling irradiance at 490 nm (Kd_

The diffuse attenuation coefficient for downwelling irradiance over the first optical atte

Inherent Optical Properties (IOPs; m^{-1})

The spectral marine absorption and backscattering coefficients of water column constit

Particulate Organic Carbon (POC; mg m^{-3})

The concentration of particulate organic carbon.

Particulate Inorganic Carbon (PIC; mol m^{-3})

The concentration of particulate inorganic carbon.

Photosynthetically Available Radiation (PAR; Einstein m^{-2} d^{-1})

Daily mean photosynthetically available radiation (PAR) at the ocean surface.

Instantaneous Photosynthetically Available Radiation (iPAR; Einstein m^{-2}

PAR the ocean surface at the time of the satellite observation. MODIS only.

Normalized Fluorescence Line Height (nFLH; mW cm^{-2} μm^{-1} sr^{-1})

Relative measure of water-leaving radiance associated with chlorophyll fluorescence. M

Remote Sensing Reflectance (Rrs; sr^{-1})

The at-surface spectral remote-sensing reflectances observed by the satellite instrumen[t] correction. The aerosol optical thickness and Ångstrom data products are also describe

Standard Sea Surface Temperature Products

11 µm Sea Surface Temperature (SST; °C)

Sea surface temperature derived from long-wave (11-12 µm) thermal radiation. MODIS only.

4 µm Sea Surface Temperature (SST4; °C)

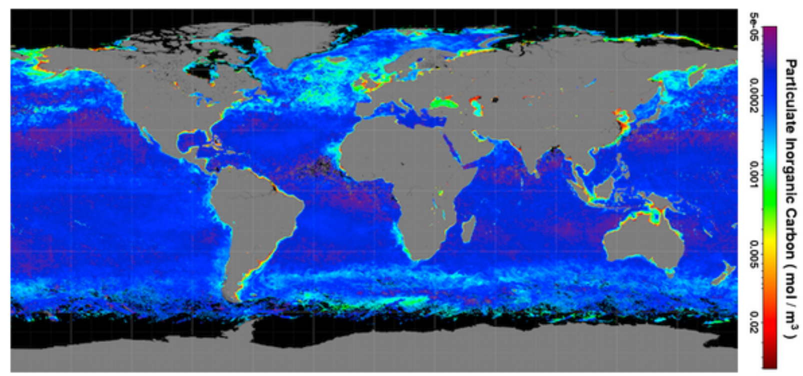
Sea surface temperature derived from short-wave (3-4 µm) thermal radiation. MODIS only.

Particulate Inorganic Carbon (PIC)

Table of Contents

1 - Product Summary

This algorithm derives the concentration of particulate inorganic carbon (PIC) in mol m^{-3}, calculated using observed in situ relationships between water-leaving radiances, spectral backscattering coefficients, and concentrations of PIC (i.e., calcium carbonate or calcite). Algorithm implementation is contingent on the availability of sensor bands near 443 and 555nm. The algorithm is applicable to all current ocean color sensors. The PIC product is included as part of the standard Level-2 OC product suite and the Level-3 PIC product suite.



MODIS Aqua PIC seasonal composite for Spring 2014

Algorithm Description

2 - Algorithm Description

The PIC algorithm is a hybrid of two independent approaches, defined here as the 2-band approach (Balch et al. 2005) and the 3-band approach (Gordon et al. 2001). The 3-band approach is used when the 2-band approach fails.

Input:

2-band approach
Normalized water-leaving radiances in two bands near 443 and 555 nm.

3-band approach
Spectral top-of-atmosphere reflectances at three wavelengths near 670, 750, and 870 nm

Output:
pic, the concentration of particulate inorganic carbon in mol m^{-3}

The 2-Band Approach:
The algorithm makes use of a precomputed look-up table, derived from in situ measurements, that contains the total backscattering coefficient for calcite at 546 nm, $b_{bc}(546)$ in m^{-1}, as a function of nLw(443) and nLw (555). The concentration of calcite (PIC) is computed by dividing $b_{bc}(546)$ by a calcite-specific backscattering coefficient (1.628 m^2 mol^{-1}), as also derived from in situ measurements.

In cases where nLw(555) is not available (OCTS, MODIS, MERIS, etc.), it is estimated from the closest native green wavelength (547, 560, and 565 nm, etc.) using the empirical relationships described here.

The 2-band algorithm may fail to retrieve PIC for two primary reasons: 1) the normalized water-leaving radiances could not be retrieved due to atmospheric correction failures or other masking conditions (e.g., clouds or land), and 2) the retrieved water-leaving radiances may be outside the range of values in the precomputed LUT. A common reason for either of these conditions is that the PIC concentration is very high, which can result in large water-leaving radiance signals in the near infrared channels that lead to poor or failed atmospheric correction. In some cases the signal is so strong in the near infrared that the observation is flagged and masked as a cloud. When these failures occur, the algorithm will attempt a retrieval using the 3-band approach, which uses a simple atmospheric correction that is more robust over bright waters.

The 3-Band Approach:
Observed TOA radiances, Lt(λ) , at three spectral bands near 670, 765, and 865 nm are converted to reflectance and then elated to the components of the radiant path reflectance through:

$$\rho_t(\lambda) = (\rho_r(\lambda) + t_s(\lambda) \times \rho_f(\lambda) \times t_s(\lambda) \times \rho_w(\lambda) + \rho_a(\lambda))t_{g_s}(\lambda)$$

where:
$\rho_t(\lambda)$ is top-of-atmosphere reflectance (measured), $\rho_r(\lambda)$ is reflectance due to Rayleigh scattering in the absence of aerosols (calculated), $\rho_f(\lambda)$ is reflectance due to whitecaps and foam (calculated), $t_s(\lambda)$ is diffuse transmittance of the atmosphere from surface to sensor (calculated), $t_g(\lambda)$ is atmospheric gas transmittance Sun to surface to sensor (calculated), $\rho_w(\lambda)$ is water-leaving reflectance (unknown), and $\rho_a(\lambda)$ is aerosol reflectance (unknown).

Aerosol and water-leaving reflectances can be expressed roughly as:

$$\rho_a(\lambda) \approx \rho_a(\lambda_0) \times \exp(a \times (\lambda_0 - \lambda))$$

and

$$\rho_w(\lambda) \approx \frac{b_b(\lambda)}{6.179 \times (a_w(\lambda) + b_b(\lambda))}$$

where:
a_w is the absorption coefficient of seawater, b_b is the total backscattering coefficient, and λ_0 = 865 nm. Backscattering by calcite and seawater can be roughly expressed as:

$$b_b(\lambda) \approx b_{bc}(546) \times \left(\frac{546}{\lambda}\right)^{1.35} + b_{bw}(\lambda)$$

Through an iterative procedure, seeded by setting the backscattering coefficients to their pure seawater values, values for $\rho_a(865)$ and a can be retrieved, and ultimately the backscattering coefficient for calcite at 546 nm, $b_{bc}(546)$ can be derived. The concentration of calcite (PIC) is then computed by dividing $b_{bc}(546)$ by an *a priori* calcite-specific backscattering coefficient (1.628 m^2 mol^{-1}).

Sensor-specific details:
As noted, the 2-band algorithm uses a common look-up table define for nLw(443) and nLw(555), and adjusts the satellite nLw retrievals as needed to account for sensor-specific differences in center wavelength relative to the look-up table indices. For the 3-band approach, the atmospheric properties and water optical properties are computed at the sensor specific band passes in the red and near-infrared, and thus the sensor differences are inherent in the implementation. The actual wavelengths used for the various sensors are shown in the table below, with the 3-band algorithm center wavelengths in parentheses.

SeaWiFS	443, 555 (670, 765, 865)
MODIS	443, 547 (667,748,869)
MERIS	443, 560 (665, 779, 865)
VIIRS	443, 551, (671, 751, 862)

Failure conditions:
The PIC product is not computed if the Level-2 flags indicate LAND, HIGLINT or CLOUDS. A failure condition is indicated in Level-2 by setting the PIC value for that pixel to the _FILLVALUE and setting the Level-2 flags to indicate PRODFAIL.

Implementation Details

3 - Implementation

Product Short Name	pic
Level-2 Product Suite	OC
Level-3 Product Suite	PIC
Level-3 Masking	ATMFAIL,LAND,HISATZEN,STRAYLIGHT,CLDICE,LOWLW, NAVWARN,ATMWARN, HISOLZEN,NAVFAIL,FILTER,HIGLINT

For further details on the implementation, go to the algorithm source code or the graphical description of the algorithm implementation in the NASA ocean color processing code (l2gen).

Main Page | Related Pages | Modules | Namespaces | Classes | Files

File List | File Members

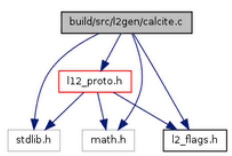
Defines | Functions

build/src/l2gen/calcite.c File Reference

(r11331/r10609)

```
#include <stdlib.h>
#include <math.h>
#include "l12_proto.h"
#include "l2_flags.h"
```

Include dependency graph for calcite.c:



Go to the source code of this file.

Defines

#define	BAD_CACO3	BAD_FLT
#define	N443	490
#define	N550	456

Functions

float	get_bbstar (float lat)
float	calcite_3b (l2str *l2rec, int32_t ip)
float	calcite_2b (l2str *l2rec, int32_t ip)
float	calcite_c (l2str *l2rec, int32_t ip)
void	calcite (l2str *l2rec, l2prodstr *p, float prod[])

Main Page | Related Pages | Modules | Namespaces | Classes | Files

File List | File Members

build/src/l2gen/calcite.c (r11331/r10609)

Go to the documentation of this file.

```
/*---------------------------------------------------------------------*/
/* calcite.c -  get calcium carbonate concentration.                   */
/*                                                                     */
/* Inputs:                                                             */
/*     l2rec - level-2 structure containing one complete scan after    */
/*             atmospheric correction.                                 */
/* Outputs:                                                            */
/*     caco3 - calcium carbonate concentration, per pixel        .     */
/*                                                                     */
/* Written by: W. Robinson, GSC, 7 Jun 2000.                           */
/*             S. Bailey, OCDPG, July 2004, conversion to C.           */
/*             B. Franz, OCDPG, Sep 2004, sensor generalization and    */
/*                implementation of 2-Band algorithm.                  */
/*                                                                     */
/*---------------------------------------------------------------------*/

#include <stdlib.h>
#include <math.h>
#include "l12_proto.h"
#include "l2_flags.h"


#define BAD_CACO3 BAD_FLT

static float pi        = PI;
static float radeg     = RADEG;
static int32_t  caco3_msk = LAND | HIGLINT | CLOUD;
static float caco3min  = 1.18e-5;     /* bcb */
static float bbstar = 4.0;            /* bcb */

/* ------------------------------------------------------------------- */
/* calcite_3b() - calcium carbonate concentration from 3-Band algorith.. */
/*                                                                     */
/* Gordon, H.R. Boynton, G.C., Balch, W.M., Groom, S.B., Harbour, D.S., */
/* Smyth, T.J., Retrieval of Coccolithophore Calcite Concentration from */
/* SeaWiFS Imagery, GRL, 28, 8, 1587-1590.                             */
/*                                                                     */
/* ------------------------------------------------------------------- */

float get_bbstar(float lat) {
    static float c[] = {8.701E-01,1.200E-01,-5.999E-04,-6.606E-04,
            4.202E-05,-1.150E-06,1.614E-08,-1.138E-10,3.196E-13};
```

Assessment

4 - Assessment

A limited set of Level-2 satellite-to-in-situ match-up validation results are av
validation tool of the SeaWiFS Bio-Optical Archive and Storage System (Sea
are provided below.

- SeaWiFS
- MODIS Aqua
- MODIS Terra
- VIIRS
- OCTS
- CZCS
- MERIS

SeaBASS

SeaBASS Search

Home | Data Users | Data Contributors | Data Search | NOMAD | Data Archive | Wiki | Lists | Contact Us

MODIS Aqua vs. In situ

Dates	1930-01-01 to 2015-05-08
Date Archived	2000-01-01 to 2015-05-08
North	90
South	-90
West	-180
East	180
Depth	0 to 10000
Output products	pic
Investigator/Experiment/Cruise	ALL
Data Source	seabass
Minimum valid satellite pixels	50
Maximum solar zenith angle	70
Maximum satellite zenith angle	56
Maximum time difference between satellite and in situ	3
Maximum coefficient of variation of satellite pixels	0.15
Maximum irradiance difference between measured and modeled	20
Maximum windspeed	35
Satellite version	R2013.1
Most Recent Data Update	2014-11-07 16:20:27

Permalink | Back to Validation Search

Search Results

Total number of matchups: 17

Date format is YYYY-MM-DD, time format is HH:MM:SS, and times are GMT.
Only products with matchups will be displayed.

pic | Download Stats/Plots | Generate Data File (.csv) | Download Data File

Statistics | Data

Product Name	MODIS Aqua Range	In situ Range	#	Best Fit Slope	Best Fit Intercept	R^2	Median Ratio	Abs % Difference	RMSE
pic	0.00004, 0.00130	0.00003, 0.00065	17	1.92308	-0.00003	0.52004	1.70518	70.51802	0.00027

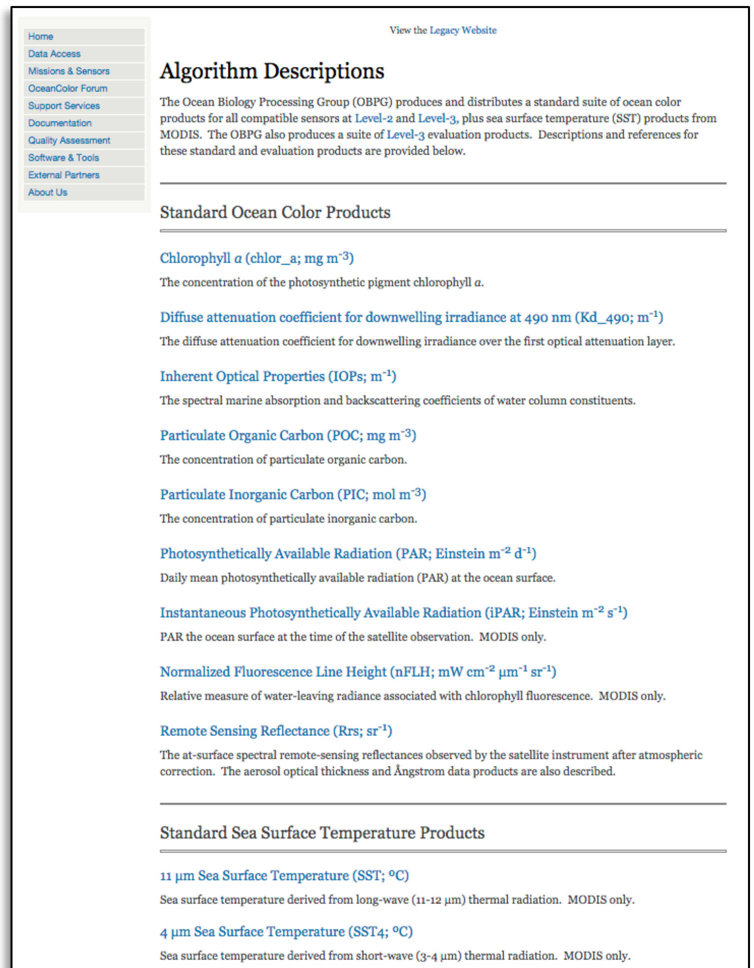
The linear regression algorithm has been changed to reduced major axis.

Action for Team Members

Algorithm POCs please review and revise existing algorithm description documents for all current standard products.

http://oceancolor.gsfc.nasa.gov/cms/atbd

$R_{rs}(\lambda)$	*Franz*
Chlorophyll *a*	*Werdell, Hu*
$K_d(490)$	*Werdell*
POC	*Stramski (Franz)*
PIC	*Balch*
PAR	*Frouin*
iPAR	*Bailey (Franz)*
nFLH	*Westberry*
IOPs	*Werdell*
SST (11um)	*Minnett (Kilpatrick)*
SST (4um)	*Minnett (Kilpatrick)*



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PAR the ocean surface at the time of the satellite observation. MODIS only.

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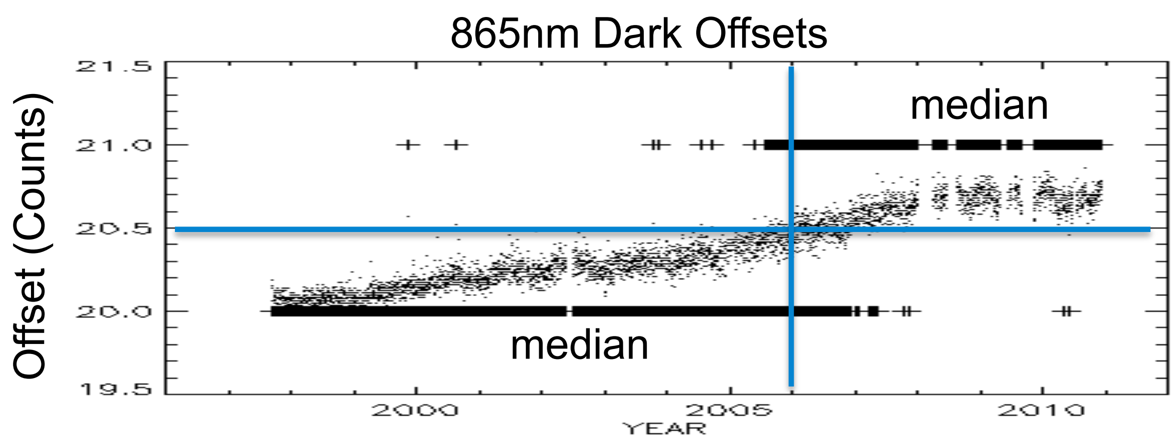
Sea surface temperature derived from long-wave (11-12 µm) thermal radiation. MODIS only.

4 µm Sea Surface Temperature (SST4; °C)
Sea surface temperature derived from short-wave (3-4 µm) thermal radiation. MODIS only.

Instruments and Calibration

R2014.0 SeaWiFS Calibration Changes

- enhanced tracking of dark offset changes (now tracking at the sub-count level, using per detector measurements from intergain cal).

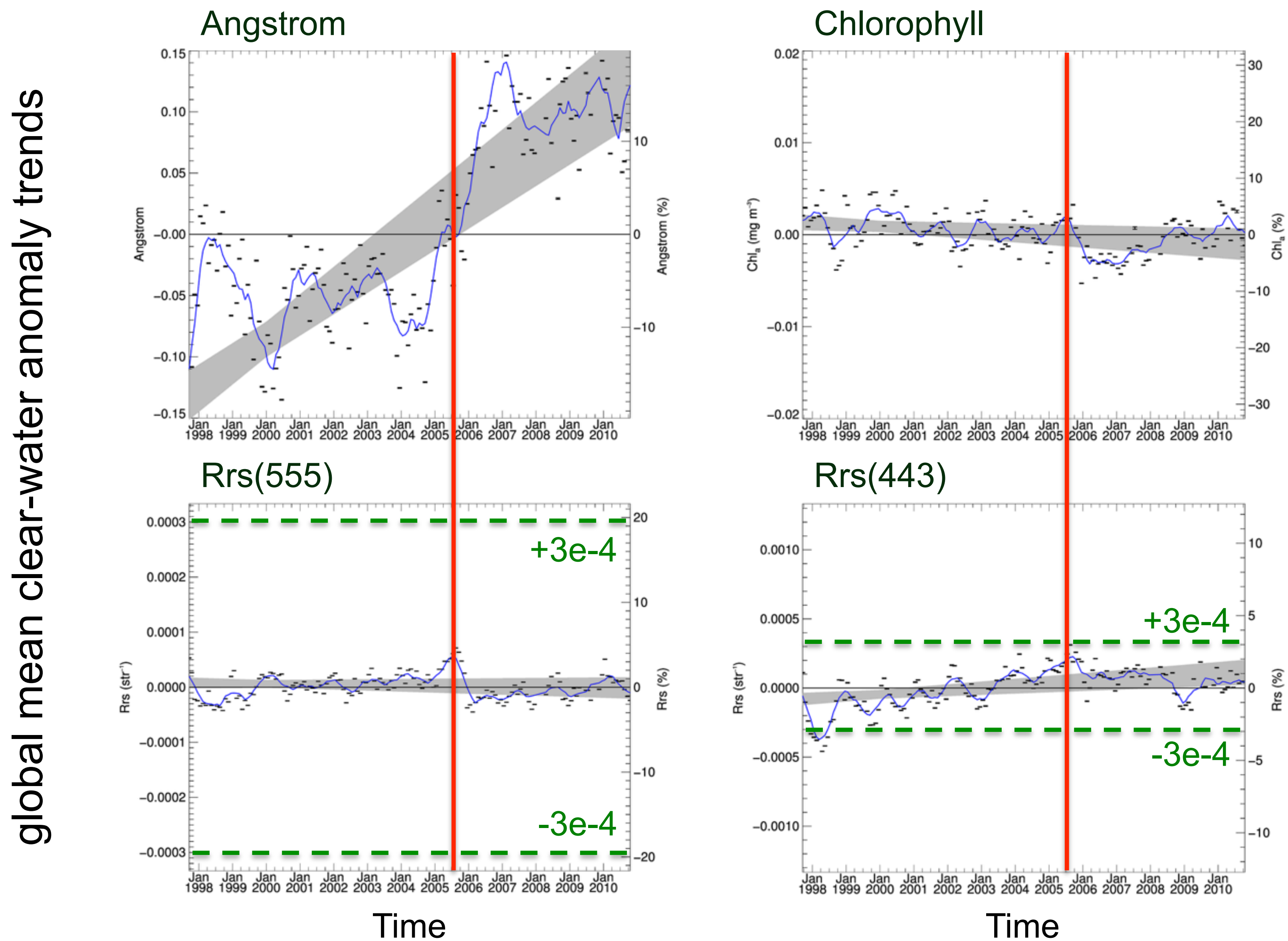


- correction for time-dependent change in system spectral response due to spectral dependence of long-term responsivity change (>20% in NIR, 3% in blue). Largest impact at 865nm (0.6% life of mission).

- updated correction for differences in degradation of the lunar and earth-view commanded gain for the 765nm channel.

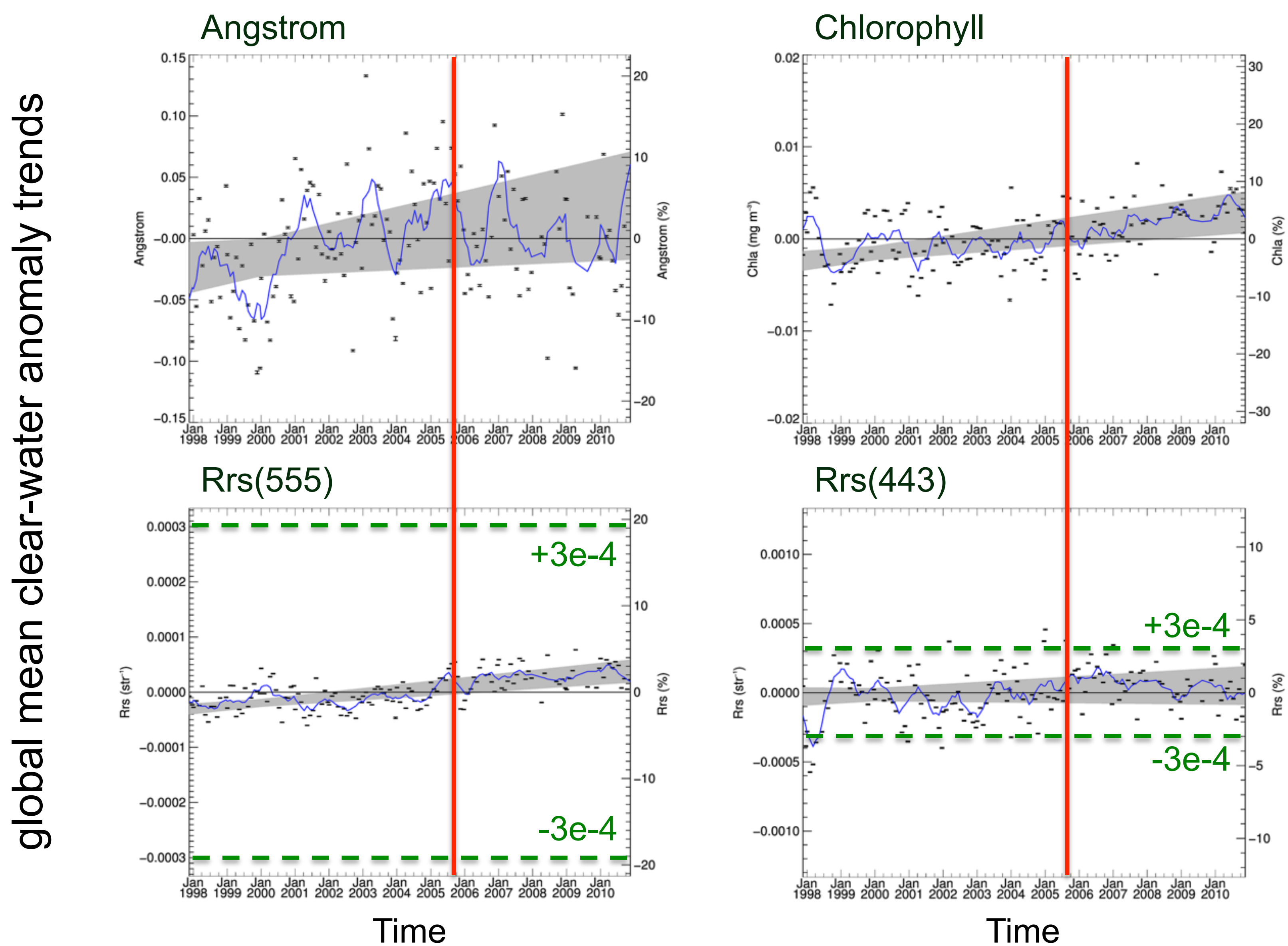
SeaWiFS R2010.0 Radiometric Instability Issue

determined to be due to 1-count shift in avg dark offset



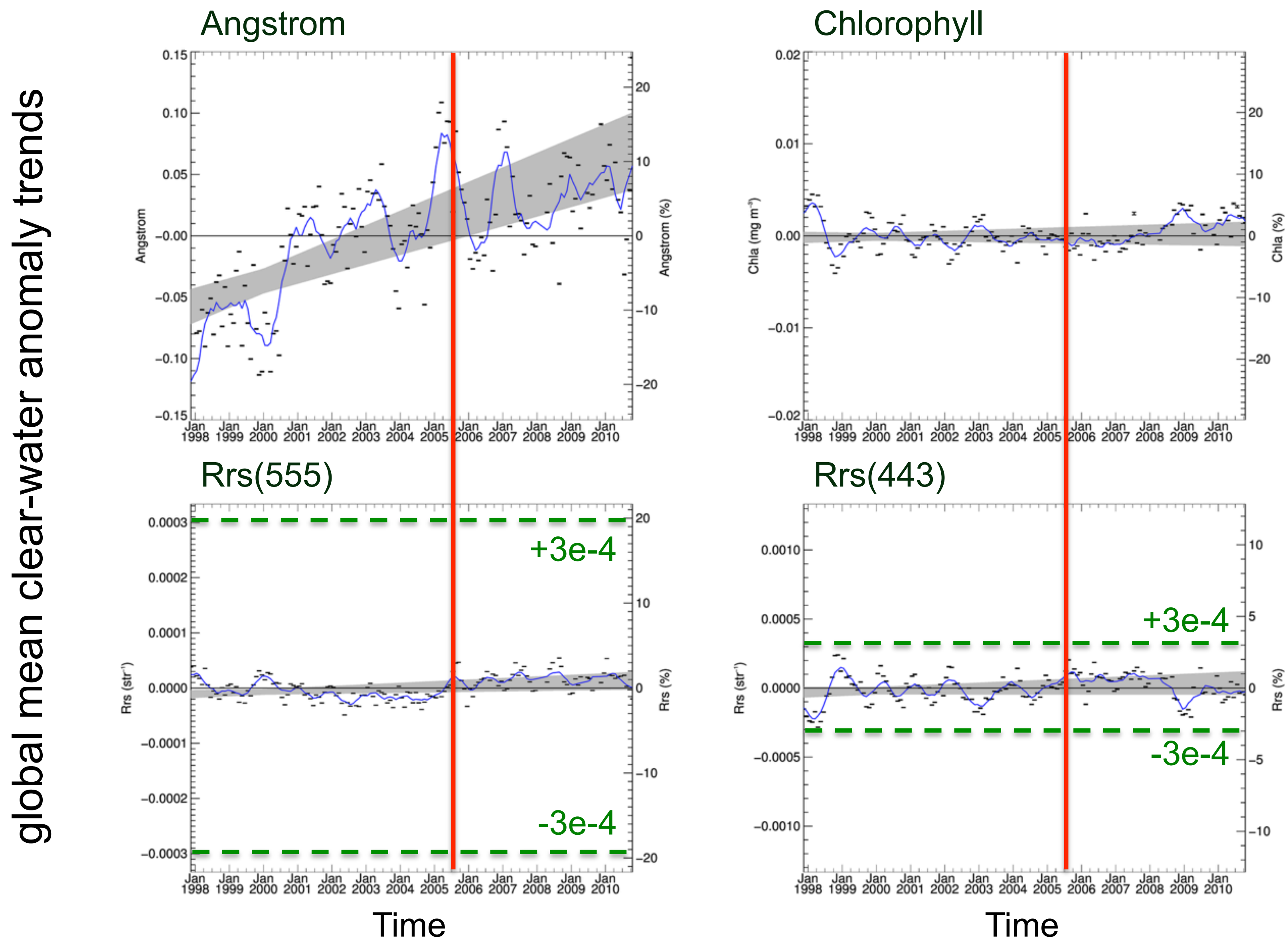
SeaWiFS R2014.0 Recalibration (1)

sub-count dark-offset changes determined from intergain cal



SeaWiFS R2014.0 Recalibration (2)

correct for effect of changing system spectral response



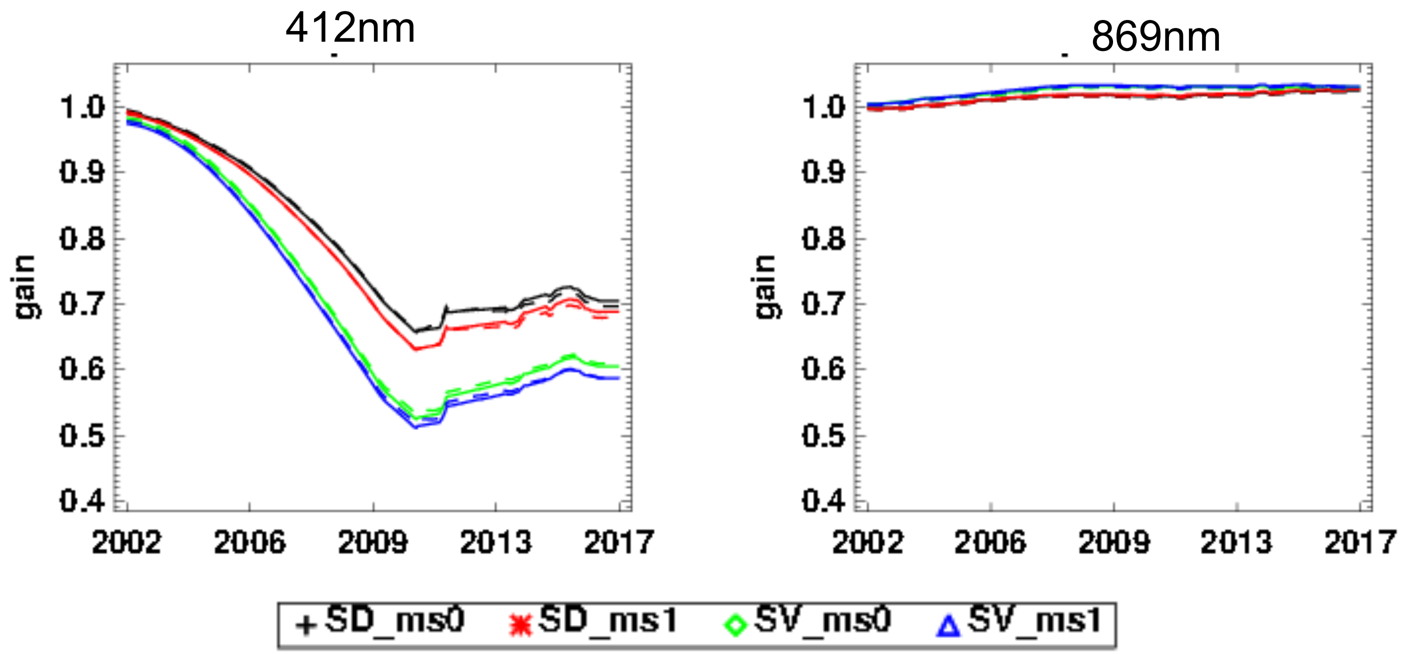
MODIS calibration: Aqua and Terra

- OBPG uses MCST calibration as starting point for MODIS Aqua, then applies minor corrections derived from a cross-calibration of MODIS Aqua to its own Level-3.

- MODIS Terra calibration difficult due to extreme degradation (primary mirror and solar diffuser)

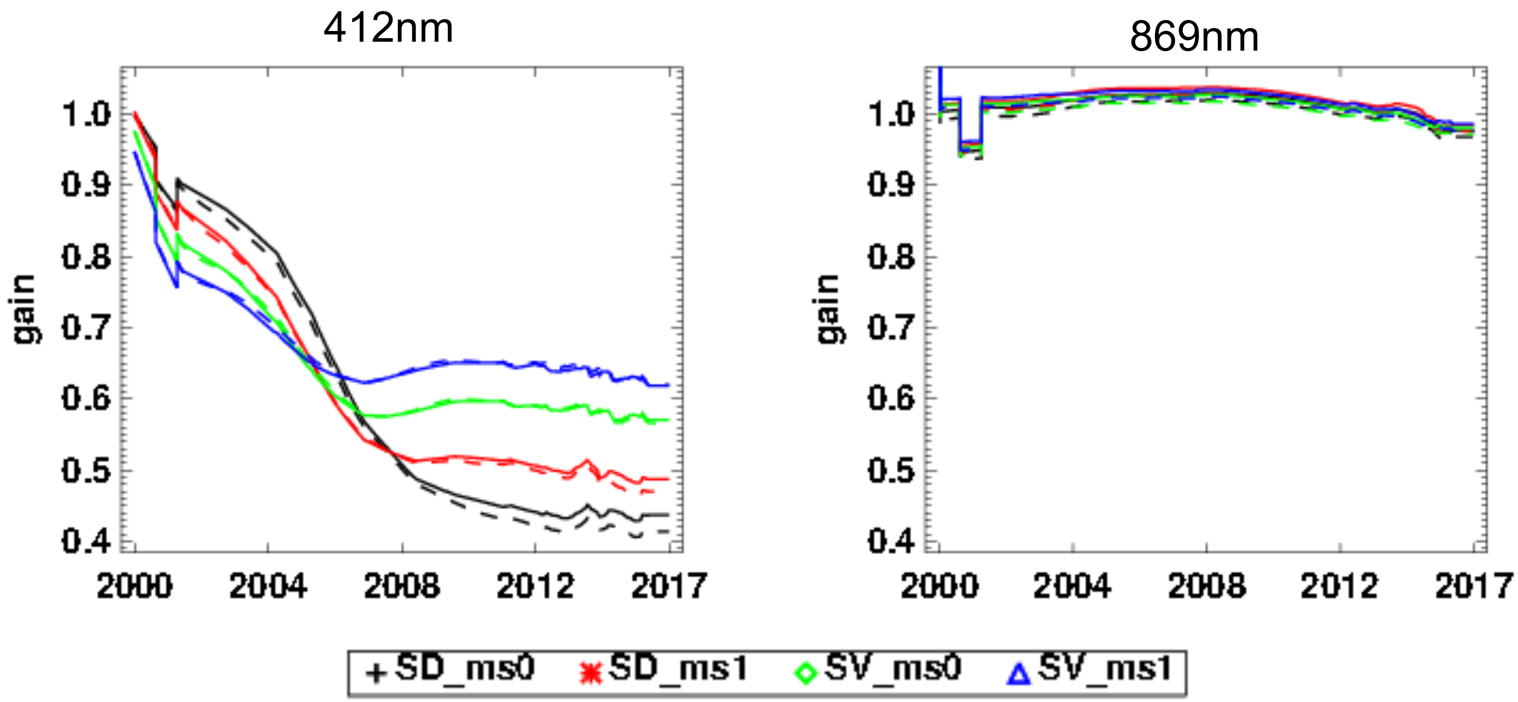
- OBPG uses MCST calibration as starting point for MODIS Terra, then overwrites it with cross-calibration to SeaWiFS (up to Jan. 2004) and MODIS Aqua afterwards. A temporally changing polarization correction is derived and applied as well. Only correction to NIR bands is striping reduction.

MODIS calibration: Aqua trends



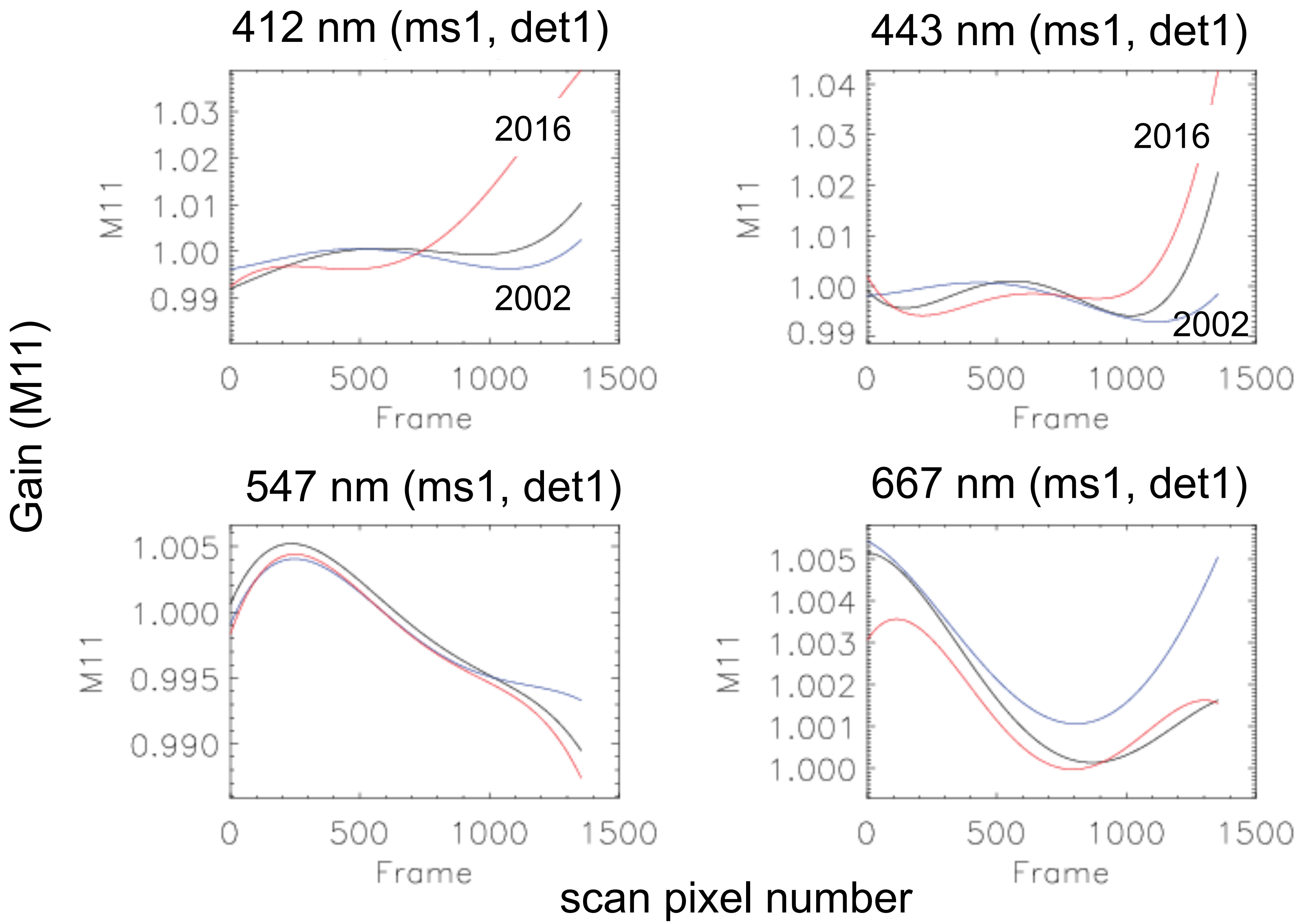
- MODIS Aqua gain trends for the short wavelengths vary strongly with scan angle, mirror sides are similar
- MCST uses lunar measurements and desert sites for gain trending of 412-443nm bands
- NIR gain trending (with solar diffuser) is less of a concern
- Cross-calibration correction is plotted (dashed), but small

MODIS calibration: Terra trends



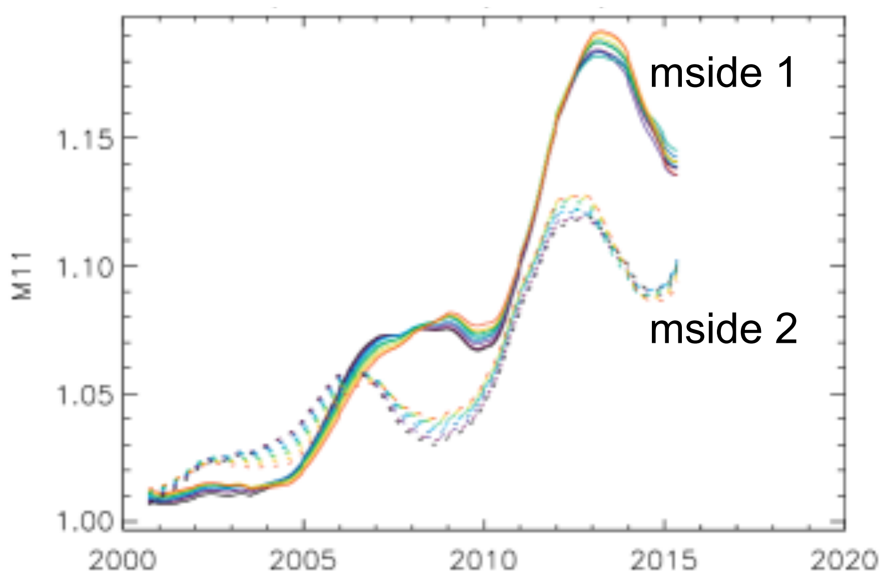
- Dashed lines include crosscalibration correction
- MODIS Terra gain trends for the short wavelengths vary strongly with scan angle and mirror side
- NIR gain trending (with solar diffuser) is less of a concern

MODISA temporal correction to response versus scan derived through flat-fielding calibration



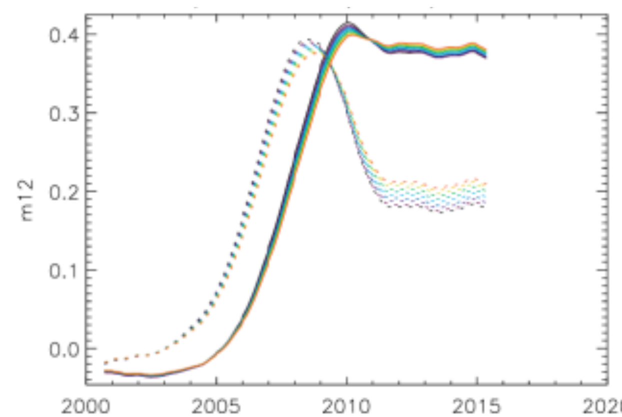
MODIST correction to RVS and polarization sensitivity derived through cross-calibration

M11 (412 nm)

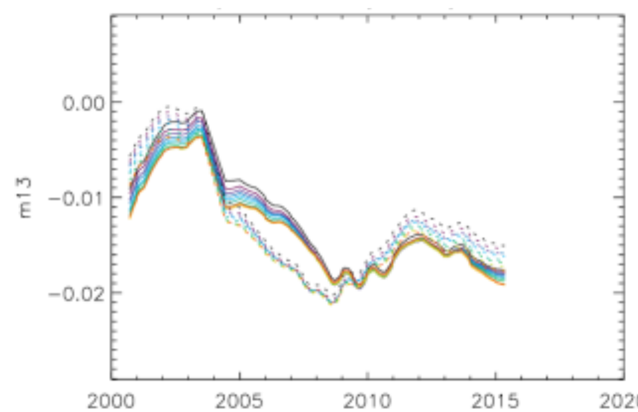


Time (Years)

m12 (412 nm)



m13 (412 nm)



Time (Years)

Temporal trend at Solar Diffuser AOI

VIIRS R2014.0 calibration

Significantly improved instrument calibration developed for ocean color through re-analysis of VIIRS prelaunch and on-orbit calibration.

1) Based on solar calibration, corrected with lunar calibration.

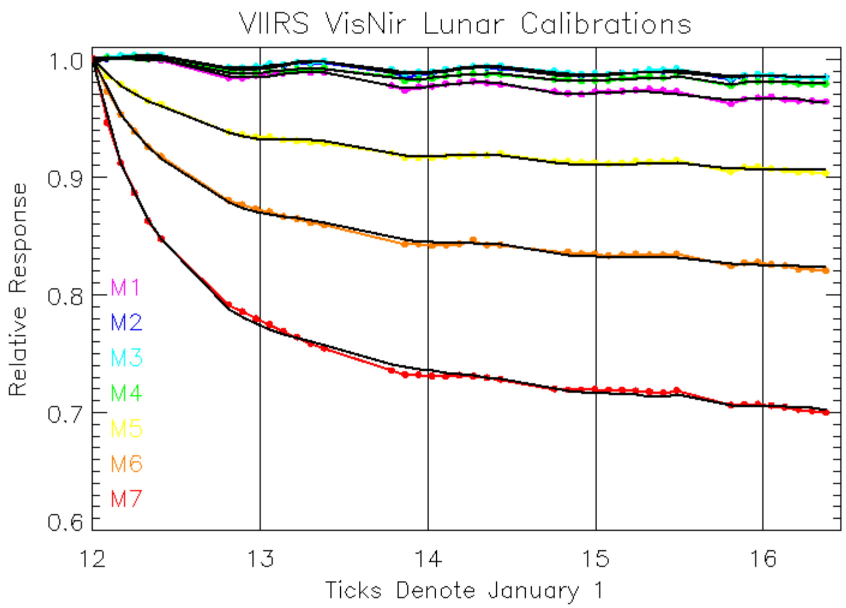
2) Incorporating advancements in solar and lunar calibrator knowledge (solar diffuser stability, solar unit vector fix, lunar libration corrections, etc.).

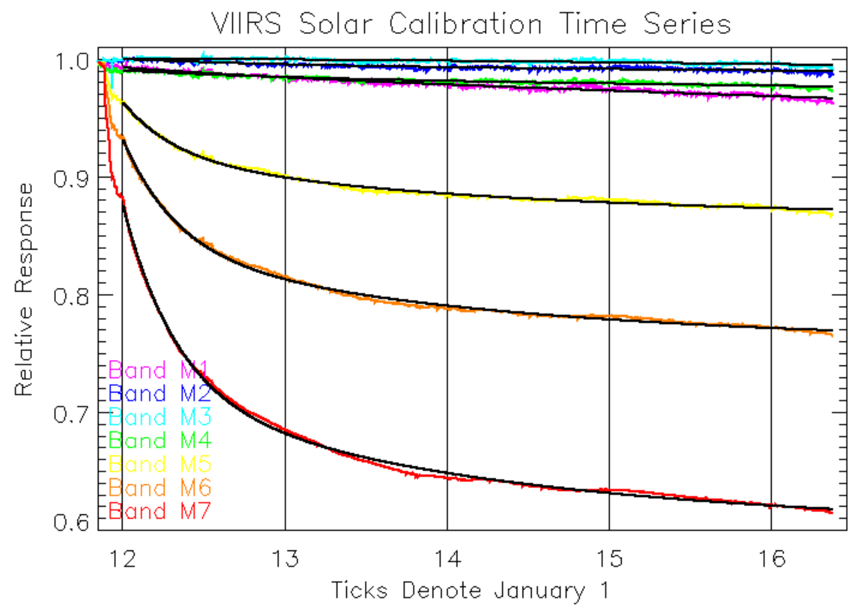
3) implemented as a continuous calibration model that allows for extrapolation into the future (improved NRT calibration quality).

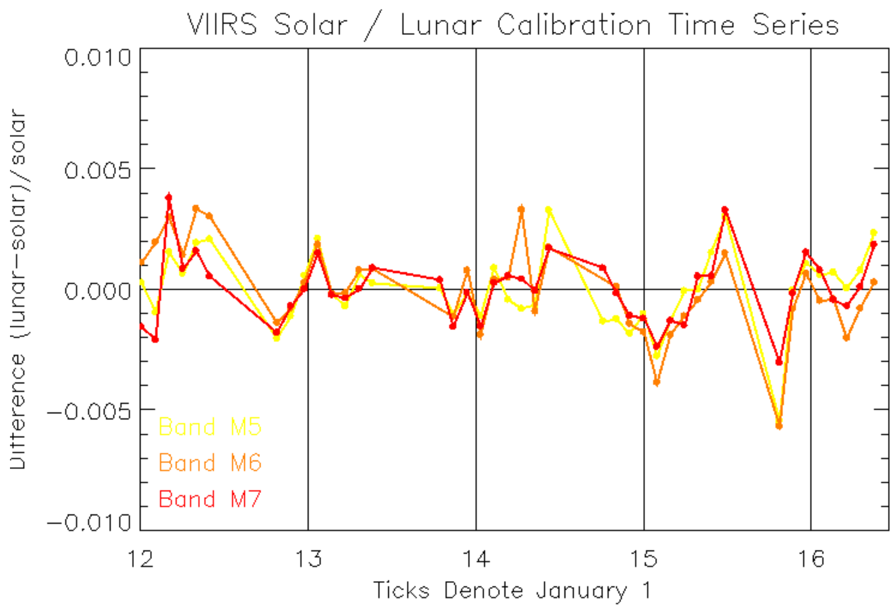
4) Including corrections for relative detector and mirror-side calibration to reduce image striping artifacts.

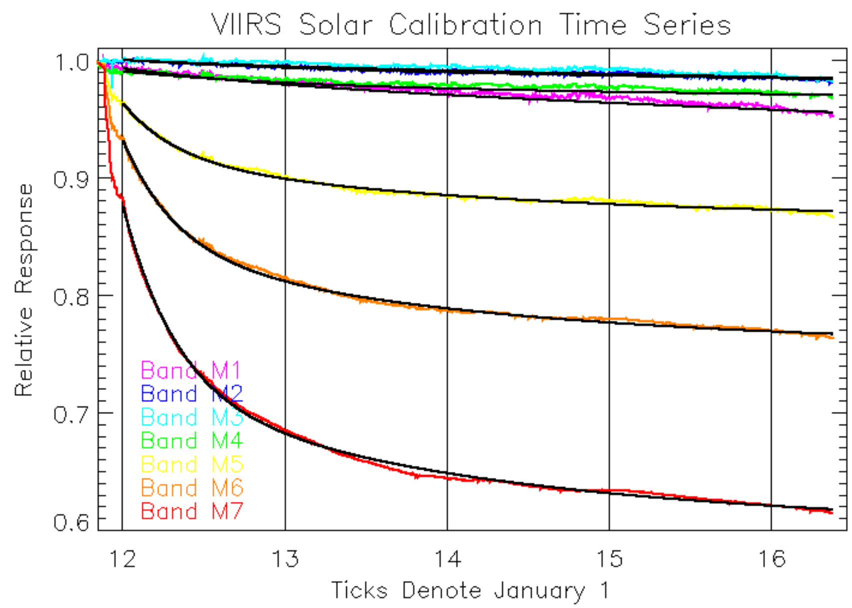
Robert E. Eplee, Kevin R. Turpie, Gerhard Meister, Frederick S. Patt, Bryan A. Franz, and Sean W. Bailey, "On-orbit calibration of the Suomi National Polar-Orbiting Partnership Visible Infrared Imaging Radiometer Suite for ocean color applications," Appl. Opt. 54, 1984-2006 (2015)

VIIRS Band M5-M7 Calibration Time Series

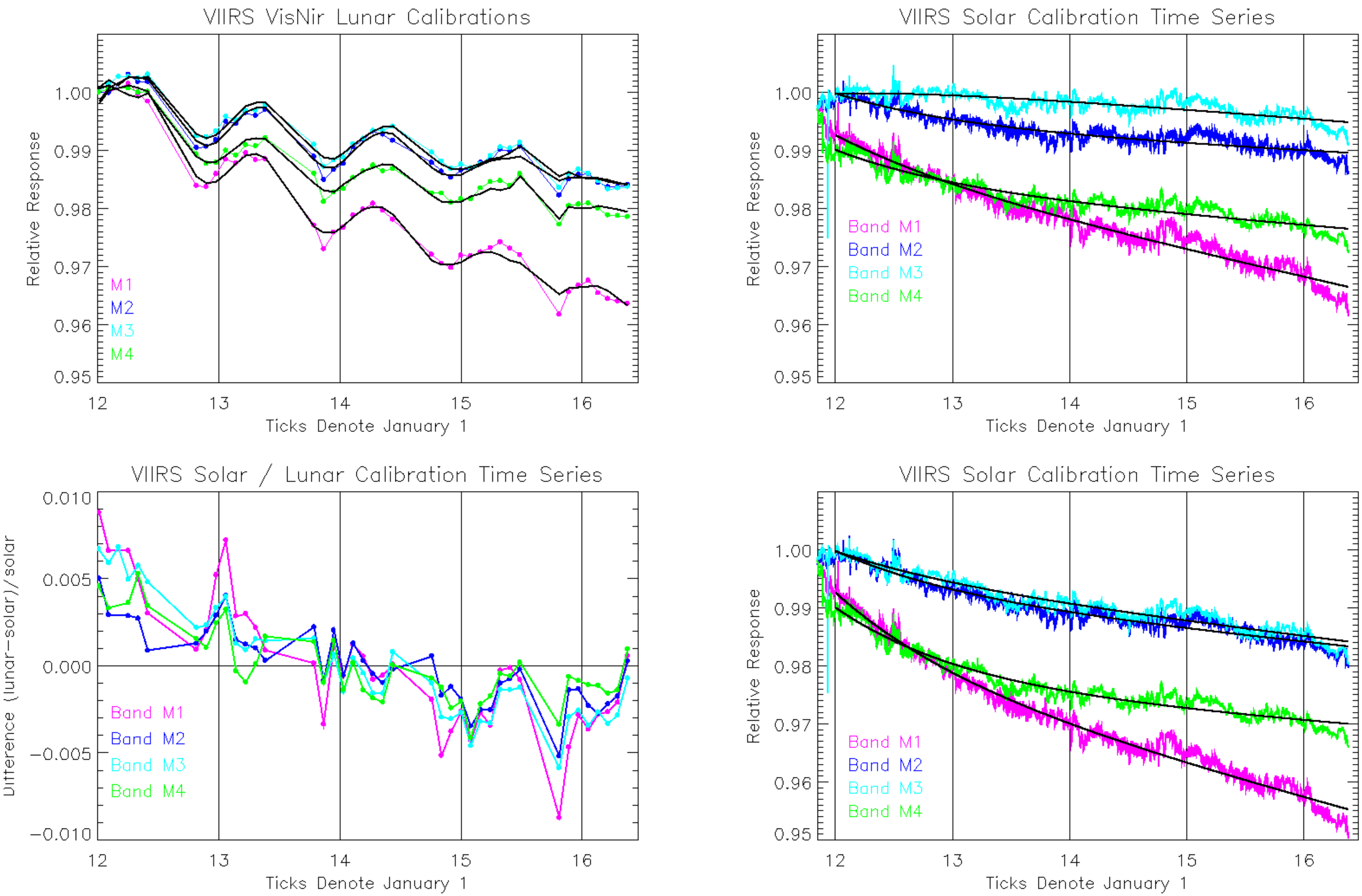




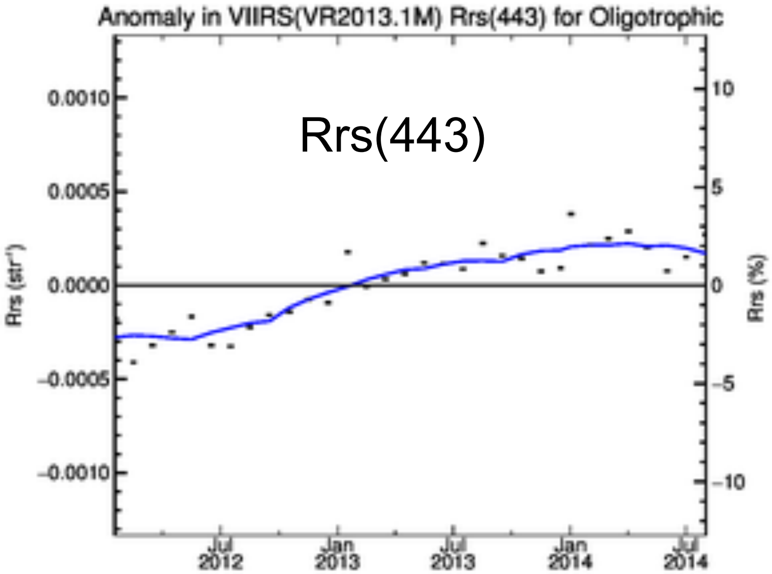




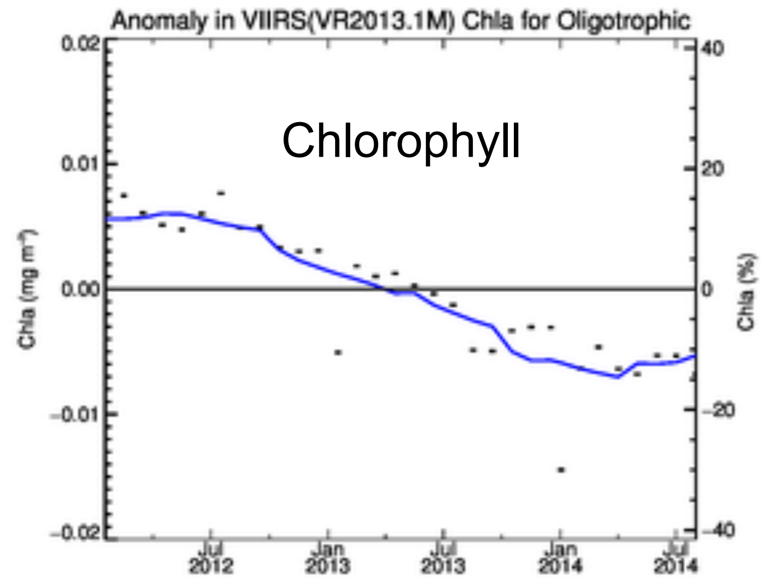
VIIRS Band M1-M4 Calibration Time Series

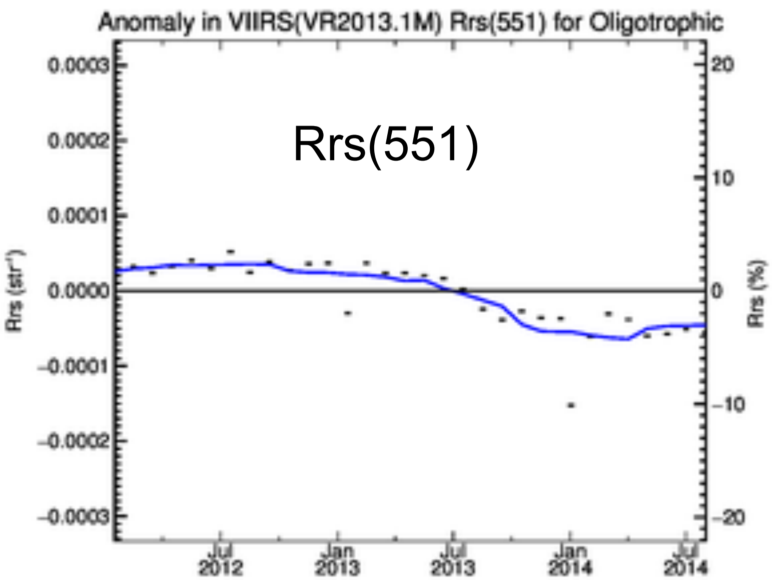


VIIRS Clear-Water Rrs Anomaly Trends

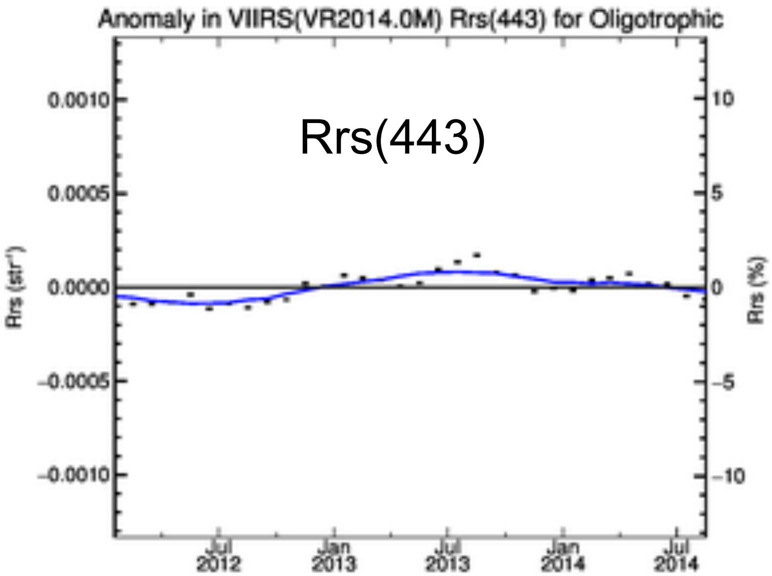


Before Reprocessing
R2013.1





VIIRS Clear-Water Rrs Anomaly Trends



After Reprocessing
R2014.0